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THE UNIVERSITY OF ALBERTA

TRANSIENTS IN DOUBLY EXCITED INDUCTION MACHINES

by

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A THESIS

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ABSTRACT

Brief consideration is given to the possibility of using alternating current asynchronous interconnections of alternating current systems and the desired properties of such asynchronous connectors are listed. It is seen that a polyphase wound rotor induction machine, operating in the doubly excited mode, should provide the desired properties.

Differential equations are derived to predict the behaviour of a standard wound rotor induction machine when operating in the doubly excited mode. From the differential equations a program for an electronic stored program digital computer was written.

The transient currents, rotor accelerations, rotor velocities and rotor displacements are considered from the moment two systems, at slightly different frequencies, are paralleled through the machine. The same phenomena are studied when both systems experience a line-to-line fault, at the machine, at the moment of paralleling. In both cases it was assumed that stator currents had achieved steady state before paralleling the rotor circuit.

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LIST OF SYMBOLS EMPLOYED

IN THIS PAPER

λ Flux Linkage (Volt-Seconds)

L Coefficient of Self Inductance (Henries)

i Instantaneous Current (Amperes)

M Coefficient of Mutual Inductance (Henries)

j A Complex Operator Defined as $\sqrt{-1}$

ψ A Complex Operator Defined as $\cos(\frac{2\pi}{3}) + j \sin(\frac{2\pi}{3})$

D The Time Derivative $= \frac{d}{dt}$

r Resistance (Ohms)

ϕ The Electric Angular Displacement Measured from the Stator to Rotor, Phase "a" of Stator to Phase "a" of Rotor (Radians)

W Work or Energy (Joules)

p Number of Poles

J Polar Moment of Inertia

R Damping Function

K A Proportionality Constant

α A Subscript to Denote Stator

β A Subscript to Denote Rotor

1 Used as a Subscript to Denote a Positive Sequence Component

2 Used as a Subscript to Denote a Negative Sequence Component

o A Subscript to Denote a Zero Sequence Component

INTRODUCTION

Two schemes are in use for interconnections of synchronous alternating current systems. These schemes use either extra high voltage direct current or extra high voltage synchronous alternating current. This paper is concerned with a device which, theoretically, could be a principal component of an asynchronous alternating current interconnection.

Two synchronous alternating current systems would be asynchronously interconnected if each system could be operated at a frequency independent of the other system, and if power could be transferred from one system to the other after such an interconnection has been made.

One possible type of asynchronous interconnection is composed of two synchronous machines coupled through a fluid drive. Such a system is truly an asynchronous connector because the fluid drive permits one shaft to rotate independently of the other shaft; because the fluid drive permits transfer of mechanical power; and finally because either synchronous machine can behave either as a synchronous motor or as a synchronous alternator.

The asynchronous interconnection composed of two synchronous machines coupled through a fluid drive has the following disadvantages:

(a) There are two machines each having nearly the same iron and copper losses.

(b) There are two direct current fields which must be excited in order to maintain synchronism.

(c) There are two shafts rotating at synchronous speed and the friction and windage losses are significant.

(d) Fluid drives generally do not allow the "load" sides of the drives to rotate faster than the "motor" sides of the drives and they have not been designed to transmit more than a few megawatts.

(e) Synchronous machines sustain fault KVA and any such fault would be supplied by two electric systems.

The writer sought a device which would have the properties of an asynchronous connector without the above disadvantages. The ideal alternating current asynchronous connector would have the following properties:

(a) One shaft would revolve at slip speed.

(b) The device would not convert electric power to mechanical power at any point in the connector.

(c) The asynchronous device would not require direct current excitation.

(d) A fault on either electric system would be electrically isolated from the other system by the asynchronous connector.

In the conventional wound rotor induction motor there are four principle components:

(a) A stationary part called the stator has nearly identical phase resistances and has nearly identical phase reactances. The stator

phase windings are nearly symmetrically placed.

(b) A rotating part called the rotor has nearly identical phase resistances and has nearly identical phase reactances. The rotor phase windings are nearly symmetrically placed.

(c) A set of slip rings, to which the rotor windings are connected, and a set of brushes, to which the slip rings electrically connect, are used to insert impedances into the rotor circuits.

(d) External impedances of nearly equal phase values are inserted into the rotor circuit to control rotor speed.

Doubly excited wound rotor induction machine operation is said to exist when excitation from separate sources is applied to the rotor and stator.

If the rotor of a doubly excited wound rotor induction machine rotates at the slip speed the rotor fluxes are in time phase with the stator fluxes and the mutual fluxes. Under such circumstances the rotor speed will be given by the formula

$$n_s = \frac{120}{p}(f_1 - f_2)$$

where n_s is the rotor speed in revolutions per minute

p is the number of poles in both stator and rotor

f_1 is the frequency in cycles per second applied to the stator

f_2 is the frequency in cycles per second applied to the rotor.

Clearly f_1 and f_2 can be different and independent. Therefore the first criterion of an asynchronous connector is satisfied. Further,

if the rotor rotates at slip speed and the ratio of stator to rotor voltages changes, the air gap flux density changes and a change in magnitude of KVA flow results. Generally speaking this implies a change in power flow and a change in KVAR flow.

The objects of this research are as follows:

(a) The steady state advantages and disadvantages of a doubly-excited wound rotor induction machine are fairly easily studied, but the starting phenomena are not so readily studied and the starting phenomena form the main subject of this research.

(b) The fundamental problem is to select a suitable asynchronous connector. This research indicates that the conventional doubly-excited induction machine is likely to be unstable.

(c) The advantages and disadvantages of asynchronous interconnections are numerous but difficulties can be resolved only through increased interest in the subject. One object of this paper is to stimulate enough interest that the disadvantages may be overcome.

CHAPTER I

KIRCHHOFF'S LAW AND DERIVATION OF VOLTAGE EQUATIONS

I. INTRODUCTION

The following considerations are necessary before analysis can be attempted:

(a) One must be able to determine the instantaneous currents and voltages in both the stator and rotor.

(b) One must be able to predict the position of the rotor and its velocity at any instant in order to determine the electrical torque induced and the retarding mechanical torques.

In this chapter derivations are presented which enable one to predict the currents flowing at any instant. Induced torques are studied in Chapter II.

Throughout this paper the machine is assumed to be connected as in figure 1. The rotor body is assumed to rotate at angular speed ω electrical radians per second and positive ω is assumed to be counter-clockwise.

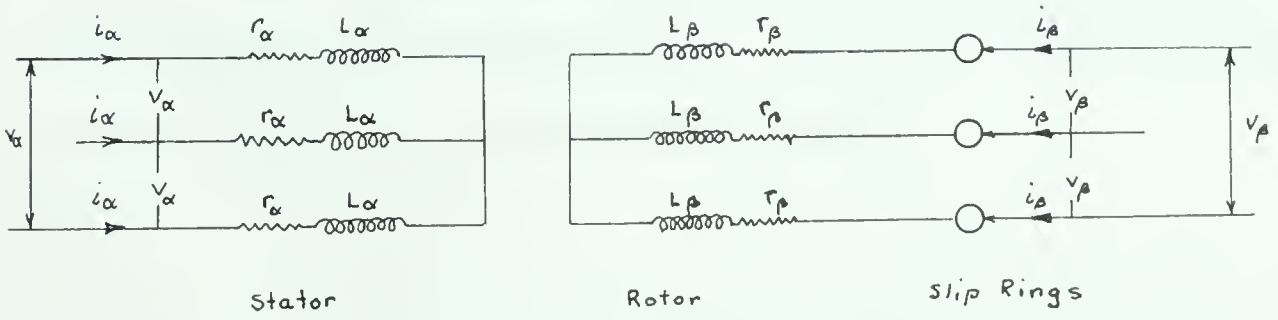


Fig. 1 Electrical Circuit Diagram of a Doubly Excited Wound Rotor Induction Machine

II. RESTRICTIONS

All of the formulae in Chapters I and II are dependent on the assumptions that:

(a) Stator and rotor have negligible hysteresis and eddy current losses.

(b) The air gap is uniform and the air gap flux is sinusoidally distributed in space.

(c) The stator and rotor are perfectly symmetrical with respect to resistance and inductance as well as physical location of the phase windings.

(d) The resistances and inductances of stator and rotor windings are independent of current magnitude and frequency.

(e) The self-inductances of stator and rotor windings are independent of their relative positions whereas the mutual inductance between stator winding and a rotor winding varies as the cosine of the electrical angle between them.

(f) The capacitances produced by proximal locations of windings one to another have negligible effects.

(g) The impedance of sources of potential for stator and rotor are negligible and hence the stator and rotor may be regarded as being connected to semi-infinite sources.

III. THREE PHASE WINDINGS

The "a" phase flux linkage λ_a which is the result of currents in phases "a", "b" and "c" under the assumptions in Section II is given by

$$\lambda_a = L_a' i_a + M_{ab} i_b + M_{ac} i_c \qquad (1)$$

where L_a' is the self-inductance of phase "a"

M_{ab} is the mutual inductance between phase "a" and phase "b"

M_{ac} is the mutual inductance between phase "a" and phase "c"

and where

inductances are in henries

currents are in international amperes[1].

With the assumptions of Section II being made,

$$M_{ab} = M_{ac} = M_{bc}$$

By Kirchhoff's current law, flux through phase "a" caused by positive current in phase "b" would be oppositely directed to flux through phase "a" caused by positive current in phase "a" itself. Also by Kirchhoff's current law

$$i_b + i_c = - i_a$$

and in consequence of the formula

$$M_{ab} = M_{ac}$$

---

[1] Throughout this paper the MKS system of units is used. If CGS units were used, the units would be abhenry and abampere respectively. The potential would be in abvolts for CGS units and volts for the MKS system.

it is obvious that

$$\lambda_a = (L_a' - M_{ab})\, i_a \qquad (2)$$

Equation (2) is valid provided no "neutral" current flows. If neutral currents flow, equation (1) becomes

$$\lambda_{ao} = L_a' i_{ao} + M_{ab} i_{bo} + M_{ac} i_{co} \qquad (3)$$

Since $i_{bo} = i_{co} = i_{ao}$ by definition

$$\lambda_{ao} = (L_a' + 2M_{ab})\, i_{ao} \qquad (4a)$$

Since the flux through phase "a" caused by positive current in phase "b" is oppositely directed to flux through phase "a" caused by positive current in phase "a" itself, M_{ab} and M_{ac} in equation (1) must be assumed to be negative. If M_{ab} and M_{ac} are assumed negative then

(a) $(L_a' - M_{ab}) > 0$

(b) $(L_a' - M_{ab}) > (L_a' + 2M_{ab})$

(c) $(L_a' + 2M_{ab}) > 0$ (by Lenz's Law)

(d) $(L_a') > 2M_{ab}$ because $M_{ab} < 0$ and $L_a' + 2M_{ab} > 0$

IV. MUTUAL FLUX LINKAGES

For three phase windings the mutual flux linkage with rotor phase "a" caused by currents in a symmetrical three phase stator winding are as follows:

$$\lambda_{\beta a} = M_{\beta a \alpha a}\, i_{\alpha a} + M_{\beta a \alpha b}\, i_{\alpha b} + M_{\beta a \alpha c}\, i_{\alpha c} \qquad (4)$$

Equation (4) is valid for all degrees of balanced or unbalanced three phase circuits .

Assuming sinusoidal flux distribution in the air gap, the following equations are obvious:

$$M_{\beta a \alpha a} = M' \cos\phi = \frac{M'}{2}(e^{j\phi} + e^{-j\phi})$$

$$M_{\beta a \alpha b} = M' \cos(\phi - \tfrac{2\pi}{3}) = \frac{M'}{2}(e^{j(\phi - \frac{2\pi}{3})} + e^{-j(\phi - \frac{2\pi}{3})})$$

$$= \frac{M'}{2}(\psi^2 e^{j\phi} + \psi e^{-j\phi}) \qquad \text{(see fig. 2)}$$

similarly

$$M_{\beta a \alpha c} = \frac{M'}{2}(\psi e^{j\phi} + \psi^2 e^{-j\phi}) \qquad \text{(see fig. 2)}$$

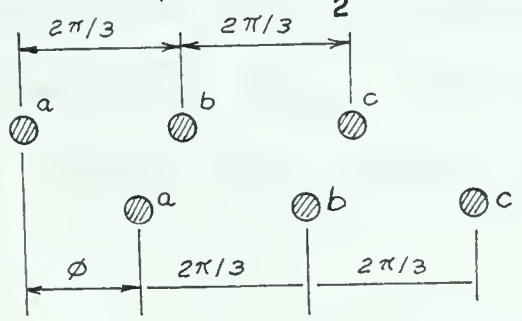


Fig. 2 Relative Orientation of Stator and Rotor Windings

by definition

$$i_{\alpha a} = i_{\alpha 1} + i_{\alpha 2} + i_{\alpha 0}$$

$$i_{\alpha b} = \psi^2 i_{\alpha 1} + \psi i_{\alpha 2} + i_{\alpha 0}$$

$$i_{\alpha c} = \psi i_{\alpha 1} + \psi^2 i_{\alpha 2} + i_{\alpha 0}$$

Substitution into equation (4) yields

$$\lambda_{\beta a} = \frac{M'}{2}(e^{j\phi} + e^{-j\phi})(i_{\alpha 1} + i_{\alpha 2} + i_{\alpha 0})$$
$$+ \frac{M'}{2}(\psi^2 e^{j\phi} + \psi e^{-j\phi})(\psi^2 i_{\alpha 1} + \psi i_{\alpha 2} + i_{\alpha 0})$$
$$+ \frac{M'}{2}(\psi e^{j\phi} + \psi^2 e^{-j\phi})(\psi i_{\alpha 1} + \psi^2 i_{\alpha 2} + i_{\alpha 0})$$

This may be shown to be equivalent to the following equation:

$$\lambda_{\beta a} = \frac{3}{2} M'(i_{\alpha 1} e^{-j\phi} + i_{\alpha 2} e^{+j\phi}) \qquad (5)$$

Similarly the following equation may be deduced:

$$\lambda_{\alpha a} = \frac{3}{2} M'(i_{\beta 1} e^{j\phi} + i_{\beta 2} e^{-j\phi}) \qquad (5a)$$

Substituting $M = \frac{3}{2} M'$ into equation (5) and (5A)

$$\lambda_{\beta a} = M \left(i_{\alpha 1} e^{-j\phi} + i_{\alpha 2} e^{j\phi} \right) \tag{6}$$

$$\lambda_{\alpha a} = M \left(i_{\beta 1} e^{j\phi} + i_{\beta 2} e^{-j\phi} \right) \tag{7}$$

Thus if the flux is sinusoidally distributed in space the mutual flux linkage is independent of the zero sequence currents in either stator or rotor since no zero sequence components occur in equations (6) and (7). While no zero sequence components occur in the air gap it is not obvious that zero sequence terms do not occur in the equation of torque. The study of torque will show that such is true. Torques are studied in Chapter II.

V. VOLTAGE EQUATIONS

Displacement currents and leakage currents through insulation are small and completely negligible. Such being the case the fall in potential between the terminals of a stator or rotor consists of two components as follows:

(a) The resistance drop ri dissipates power and provides electromagnetic damping.

(b) The variation of total flux linkage, $\frac{d\lambda}{dt}$, generates a voltage but dissipates no power.

The total flux linkage consists of two parts:

(a) The self-flux linkage is given by equation (2) and (4)

(b) The mutual flux linkage is given by equations (6) and (7).

The fall in potential between the terminals of phase "a" of the stator caused by positive, negative and zero sequence currents is as follows:

$$v_{\alpha a} = v_{\alpha 1} + v_{\alpha 2} + v_{\alpha 0} = (r_\alpha + L_\alpha D)(i_{\alpha 1} + i_{\alpha 2} + i_{\alpha 0}) + M D (i_{\beta 1} e^{j\phi} + i_{\beta 2} e^{-j\phi}) \quad (8)$$

The zero sequence flux linkages do not appear in the above equation. The corresponding equation for phase "b" of the stator is as follows:

$$v_{\alpha b} = \psi^2 v_{\alpha 1} + \psi v_{\alpha 2} + v_{\alpha 0} = (r_\alpha + L_\alpha D)(\psi^2 i_{\alpha 1} + \psi i_{\alpha 2} + i_{\alpha 0}) + M D (i_{\beta 1} \psi^2 e^{j\phi} + i_{\beta 2} \psi e^{-j\phi}) \quad (9)$$

Similarly for phase "c"

$$v_{\alpha c} = \psi v_{\alpha 1} + \psi^2 v_{\alpha 2} + v_{\alpha 0} = (r_\alpha + L_\alpha D)(\psi i_{\alpha 1} + \psi^2 i_{\alpha 2} + i_{\alpha 0}) + M D (i_{\beta 1} \psi e^{j\phi} + i_{\beta 2} \psi^2 e^{-j\phi}) \quad (10)$$

where ϕ radians has been defined (see fig. 2)

$\phi - \frac{2\pi}{3}$ radians is the electrical angle from "b" phase of stator to "a" phase of rotor

$\phi - \frac{4\pi}{3}$ radians is the electrical angle from "c" phase of stator to "a" phase of rotor.

One observes that addition of equations (8), (9) and (10) causes cancellation of all terms except those of zero-sequence. When this sum is simplified

$$v_{\alpha 0} = (r_\alpha + L_{\alpha 0} D) i_{\alpha 0} \quad (11)$$

The negative-sequence components of potential and current can be eliminated by multiplication of equation (8) by ψ and then by subtraction of equation (9) from the result. Thus:

$$v_{\alpha 1} = (r_\alpha + L_\alpha D)\, i_{\alpha 1} + MD\,(i_{\beta 1}\, e^{j\phi}) \qquad (12)$$

Similarly the negative sequence equation is as follows:

$$v_{\alpha 2} = (r_\alpha + L_\alpha D)\, i_{\alpha 2} + MD\,(i_{\beta 2}\, e^{-j\phi}) \qquad (13)$$

The corresponding rotor equations can be deduced in a similar manner and they are as follows:

$$v_{\beta 1} = (r_\beta + L_\beta D)\, i_{\beta 1} + MD\,(i_{\alpha 1}\, e^{-j\phi}) \qquad (14)$$

$$v_{\beta 2} = (r_\beta + L_\beta D)\, i_{\beta 2} + MD\,(i_{\alpha 2}\, e^{-j\phi}) \qquad (15)$$

and $$v_{\beta 0} = (r_\beta + L_{\beta 0} D)\, i_{\beta 0} \qquad (16)$$

In general the zero sequence components are negligible since the earth leakage impedance, of very large magnitude, is in series with the transient impedances above derived.

While of no practical purpose unless the star point of either stator or rotor is earthed, equation (16) was derived to demonstrate that zero sequence transient impedance, $(r_\beta + L_{\beta 0} D)$, is very small and to demonstrate the necessity for not earthing the star point of either stator or rotor of a doubly excited induction machine.

CHAPTER II

TORQUE

I. INTRODUCTION

Whenever a current carrying conductor links a magnetic field, a force is produced which attempts to minimize the linkage of flux. Several elegant methods have been evolved which predict the force produced.[1,2] Some methods employ tensor calculus to derive the force produced and others consider the torque by applying clever artifices. In the end, all methods employ the same assumptions and all employ methods derived from energy considerations. Since the methods employ the same assumptions and devolve from energy considerations, little can be gained by employing tensor notation when more easily understood methods can be employed. In the bibliography of the books below are selected references for explanation of the torque phenomenon based on tensor notation. Unfortunately none of the references explain the torque phenomena in terms of symmetrical components. To explain the torque phenomena in terms of symmetrical components requires considerable knowledge of symmetrical spinor-matrix calculus. This, then, is the main reason for abandoning tensor notation.

---

1 L. V. Bewley Tensor Analysis of Electric Circuits and Machines, The Ronald Press New York (1961)

2 G. Kron Tensors for Circuits, Dover Publications, Inc. New York 1942, copyright 1959 Dover Publications.

II. TORQUE FOR SINGLE PHASE MACHINE

Considering a single-phase rotor single-phase stator, the total stored electromagnetic energy of such a system is

$$W = \tfrac{1}{2} L_\alpha i_\alpha^2 + \tfrac{1}{2} L_\beta i_\beta^2 + M i_\alpha i_\beta \text{ joules}$$

If one assumes that the stator and rotor coils are connected to sources of electromotive force which maintain the currents i_α and i_β constant and if the rotor moves a distance dx in time dt, the increase in stored electromagnetic energy is as follows

$$dW = i_\alpha i_\beta dM \text{ joules}$$

where i_α and i_β have the same sign if they produce magnetic fields in the same direction when the displacement is zero.

Electromotive forces are generated in all coils by the variation of the mutual flux linkages and are as follows:

$$e_\alpha = -\frac{d}{dt}(i_\beta M) = -i_\beta \frac{dM}{dt} \qquad e_\beta = -\frac{d}{dt}(i_\alpha M) = -i_\alpha \frac{dM}{dt}$$

The combined electrical output of rotor and stator is therefore $(e_\alpha i_\alpha + e_\beta i_\beta)$ watts and in the time dt the energy output would be $(e_\alpha i_\alpha + e_\beta i_\beta)\,dt = -2 i_\alpha i_\beta\, dM$ joules. The work done by the applied force F' is $F' dx$ joules. Thus the total work done by the applied force F' is given by

$$F'dx = \text{(increase in stored energy)} + \text{(energy delivered)}$$
$$= i_\alpha i_\beta\, dM - 2 i_\alpha i_\beta\, dM$$
$$= -i_\alpha i_\beta\, dM$$

Newton's Third Law dictates that the applied force must be opposed by an equal developed force or that the developed force, F, is given by the equation

$$F = -F'$$

Thus $F dx = i_\alpha i_\beta dM$ joules

Hence $F = i_\alpha i_\beta \frac{dM}{dx}$ newtons

Since torque can be determined by multiplying force by effective radius then

$$T = \left\{ i_\alpha i_\beta \frac{dM}{r d\phi} \cdot r \right\} = i_\alpha i_\beta \frac{dM}{d\phi} \quad \text{newton-meters.}$$

If stator and rotor each has p poles then the rate of variation of M with respect to an angular displacement ϕ must be $\frac{p}{2}$ times as fast as if only 2 poles are in the machine. Under such circumstances

$$T = \frac{1}{2} p\, i_\alpha i_\beta \frac{dM}{d\phi} \quad \text{newton-meters}$$

where:

all angular measurements are in electrical radians

p is the number of poles on stator and rotor.

ϕ is as defined in the table of symbols and Fig. 2.

In the "ideal" machine the mutual inductance between a stator and a rotor phase is given by the equation

$$M = M' \cos\phi = \frac{1}{2} M' (e^{j\phi} + e^{-j\phi})$$

Differentiating with respect to ϕ yields

$$T = \frac{1}{2} p\, i_\alpha i_\beta\, j \frac{M'}{2} (e^{j\phi} - e^{-j\phi}) \qquad (17)$$

III. THREE PHASE WINDINGS

The three phase stator currents induce torques on the phase "a" windings of the rotor. Since a three phase stator would have three separate currents, three equations similar to equation (17) must be combined. The torque on phase "a" windings of the rotor caused by currents in phase "a" of the stator is given by

$$T_{aa} = j\frac{P}{2}\frac{M'}{2} i_{\beta a} i_{\alpha a} (e^{j\phi} - e^{-j\phi})$$

$$= j\frac{P}{2}\frac{M'}{2}(i_{\beta 1} + i_{\beta 2} + i_{\beta 0})(i_{\alpha 1} + i_{\alpha 2} + i_{\alpha 0})(e^{j\phi} - e^{-j\phi}) \qquad (17A)$$

The torque on phase "a" windings of the rotor caused by currents in phase "b" of the stator is given by

$$T_{ab} = j\frac{P}{2}\frac{M'}{2}(i_{\beta 1} + i_{\beta 2} + i_{\beta 0})(\psi^2 i_{\alpha 1} + \psi i_{\alpha 2} + i_{\alpha 0})(e^{j(\phi - \frac{2\pi}{3})} - e^{-j(\phi - \frac{2\pi}{3})})$$

$$= j\frac{P}{2}\frac{M'}{2}(i_{\beta 1} + i_{\beta 2} + i_{\beta 0})(\psi^2 i_{\alpha 1} + \psi i_{\alpha 2} + i_{\alpha 0})(\psi^2 e^{j\phi} - \psi e^{-j\phi}) \qquad (17B)$$

The torque on phase "a" windings of the rotor caused by currents in phase "c" of the stator is given by

$$T_{ac} = j\frac{P}{2}\frac{M'}{2}(i_{\beta 1} + i_{\beta 2} + i_{\beta 0})(\psi i_{\alpha 1} + \psi^2 i_{\alpha 2} + i_{\alpha 0})(e^{j(\phi - \frac{4\pi}{3})} - e^{-j(\phi - \frac{4\pi}{3})})$$

$$= j\frac{P}{2}\frac{M'}{2}(i_{\beta 1} + i_{\beta 2} + i_{\beta 0})(\psi i_{\alpha 1} + \psi^2 i_{\alpha 2} + i_{\alpha 0})(\psi e^{j\phi} - \psi^2 e^{j\phi}) \qquad (17C)$$

The torque on phase "b" windings of the rotor caused by currents in phase "a" of the stator is given by

$$T_{ba} = j\frac{P}{2}\frac{M'}{2}(\psi^2 i_{\beta 1} + \psi i_{\beta 2} + i_{\beta 0})(i_{\alpha 1} + i_{\alpha 2} + i_{\alpha 0})(e^{j(\phi + \frac{2\pi}{3})} - e^{-j(\phi + \frac{2\pi}{3})})$$

$$= j\frac{P}{2}\frac{M'}{2}(\psi^2 i_{\beta 1} + \psi i_{\beta 2} + i_{\beta 0})(i_{\alpha 1} + i_{\alpha 2} + i_{\alpha 0})(\psi e^{j\phi} - \psi^2 e^{-j\phi}) \qquad (17D)$$

The torque on phase "b" windings of the rotor caused by currents in

phase "b" of the stator is given by

$$T_{bb} = j\frac{P}{2}\frac{M'}{2} i_{\beta b}\, i_{\alpha b}\, (e^{j\phi} - e^{-j\phi})$$
$$= j\frac{P}{2}\frac{M'}{2}(\psi^2 i_{\beta 1} + \psi i_{\beta 2} + i_{\beta 0})(\psi^2 i_{\alpha 1} + \psi i_{\alpha 2} + i_{\alpha 0})(e^{j\phi} - e^{-j\phi}) \qquad (17E)$$

The torque on phase "b" windings of the rotor caused by currents in phase "c" of the stator is given by

$$T_{bc} = j\frac{P}{2}\frac{M'}{2}(\psi^2 i_{\beta 1} + \psi i_{\beta 2} + i_{\beta 0})(\psi i_{\alpha 1} + \psi^2 i_{\alpha 2} + i_{\alpha 0})(e^{j(\phi - \frac{2\pi}{3})} - e^{-j(\phi - \frac{2\pi}{3})})$$
$$= j\frac{P}{2}\frac{M'}{2}(\psi^2 i_{\beta 1} + \psi i_{\beta 2} + i_{\beta 0})(\psi i_{\alpha 1} + \psi^2 i_{\alpha 2} + i_{\alpha 0})(\psi^2 e^{j\phi} - \psi e^{-j\phi}) \qquad (17F)$$

Similarly one can deduce three more equations for the torques on windings of phase "c" of the rotor caused by the currents in phases a,b,c of the stator. These equations are as follows:

$$T_{ca} = j\frac{P}{2}\frac{M'}{2} i_{\beta c}\, i_{\alpha a}\, (e^{j(\phi + \frac{4\pi}{3})} - e^{-j(\phi + \frac{4\pi}{3})})$$
$$= j\frac{P}{2}\frac{M'}{2}(\psi i_{\beta 1} + \psi^2 i_{\beta 2} + i_{\beta 0})(i_{\alpha 1} + i_{\alpha 2} + i_{\alpha 0})(\psi^2 e^{j\phi} - \psi e^{-j\phi}) \qquad (17G)$$

$$T_{cb} = j\frac{P}{2}\frac{M'}{2} i_{\beta c}\, i_{\alpha b}\, (e^{j(\phi + \frac{2\pi}{3})} - e^{-j(\phi + \frac{2\pi}{3})})$$
$$= j\frac{P}{2}\frac{M'}{2}(\psi i_{\beta 1} + \psi^2 i_{\beta 2} + i_{\beta 0})(\psi^2 i_{\alpha 1} + \psi i_{\alpha 2} + i_{\alpha 0})(\psi e^{j\phi} - \psi^2 e^{-j\phi}) \qquad (17H)$$

$$T_{cc} = j\frac{P}{2}\frac{M'}{2} i_{\beta c}\, i_{\alpha c}\, (e^{j\phi} - e^{-j\phi})$$
$$= j\frac{P}{2}\frac{M'}{2}(\psi i_{\beta 1} + \psi^2 i_{\beta 2} + i_{\beta 0})(\psi i_{\alpha 1} + \psi^2 i_{\alpha 2} + i_{\alpha 0})(e^{j\phi} - e^{-j\phi}) \qquad (17I)$$

Addition of equations (17A), (17B), (17C), (17D), (17E), (17F), (17G), (17H) and (17I) gives

$$T = \frac{9}{4} j P M' (i_{\alpha 2}\, i_{\beta 1}\, e^{j\phi} - i_{\alpha 1}\, i_{\beta 2}\, e^{-j\phi}) \qquad (18)$$

The zero sequence currents have no direct effect on the torque developed since zero sequence currents do not occur in equation (18).

This is reasonable since no flux exists in the air gap and zero sequence currents in the rotor are in time phase and hence can produce no torque.

With regard to equation (18) the following points are observed:

(a) the sign of the exponent for the exponential function is opposed to the sequence of the stator current which multiplies the exponential function.

(b) the sign of the negative sequence stator current is positive while that of the positive sequence current is negative.

(c) zero sequence currents do not appear in the torque equation.

The above derivation is a very slight modification of the derivation as presented by Professor W. V. Lyon in section 3.6 of his text, Transient Analysis of Alternating Current Machinery.[1] The modification is the inclusion of zero sequence currents. The fact that zero sequence currents were not explicitly included by Professor Lyon is probably because they do not occur in the torque equation. This writer includes them in order to clarify his concept of the torque phenomenon.

Since zero sequence effects do not have any bearing on the

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[1] W. V. Lyon Transient Analysis of Alternating Current Machinery
The Technology Press of M.I.T.
Wiley 1954.

instantaneous torque developed and since the earth leakage impedance of a wound rotor induction machine is very large one can conclude that the zero sequence currents would be very small.

For these reasons zero sequence components are neglected henceforth.

CHAPTER III

THE MECHANICAL EQUATIONS OF MOTION

The mechanical equation of motion is given by the differential equation:

$$J\frac{d\omega}{dt} + R\omega = T_A \tag{1}$$

where J is the polar moment of inertia (ft. lbs.$_w$ sec^2 radian^{-1})

$\frac{d\omega}{dt}$ is the rate of change of angular velocity (radian sec^{-2})

R is the damping function (ft. lbs.$_w$ sec radian^{-1})

ω is the angular velocity (radian sec^{-1})

T_A is the net applied torque after "static" or kinetic friction has been deducted (ft. lbs.$_w$)

If i is used to designate the interval of time under consideration and $i-1$ is used to designate the time interval previously considered, then equation (1) can be expressed as

$$\frac{d\omega}{dt}_i = \frac{1}{J}\left(T_{A_i} - R\,\omega_{i-1}\right) \tag{1A}$$

Multiplying equation (1A) by a small time increment, Δt, gives

$$\frac{d\omega}{dt}_i \Delta t \cong \Delta\omega_i \cong \frac{\Delta t}{J}\left(T_{A_i} - R\,\omega_{i-1}\right) \tag{1B}$$

Then

$$\omega_i \cong \omega_o + \sum_{i=o}^{n} \Delta\omega_i = \omega_o + \sum_{i=o}^{n} \frac{\Delta t}{J}\left(T_{A_i} - R\,\omega_{i-1}\right) \tag{2}$$

Multiplying equation (2) by a small time increment, Δt, gives

$$\omega_i \Delta t \cong \Delta\delta_i \cong \left\{\omega_o + \sum_{i=o}^{n} \frac{\Delta t}{J}\left(T_{A_i} - R\,\omega_{i-1}\right)\right\}\Delta t$$

Then

$$\delta_i \cong \delta_o + \sum_{i=o}^{n} \Delta\delta_i \cong \sum_{i=o}^{n}\left\{\omega_o + \sum_{i=o}^{n} \frac{\Delta t}{J}\left(T_{A_i} - R\,\omega_{i-1}\right)\right\}\Delta t + \delta_o \tag{3}$$

Assuming that the torque T_{Ai} can be calculated, and assuming that R and J can be determined, equation (2) predicts the rotor velocity while equation (3) predicts the rotor displacement.

The rotor velocity is necessary in determining the induced voltage drops and the rotor displacement is necessary in determining the torque.

With reference to fig. 1 below, one can easily deduce the value of ϕ in electrical radians.

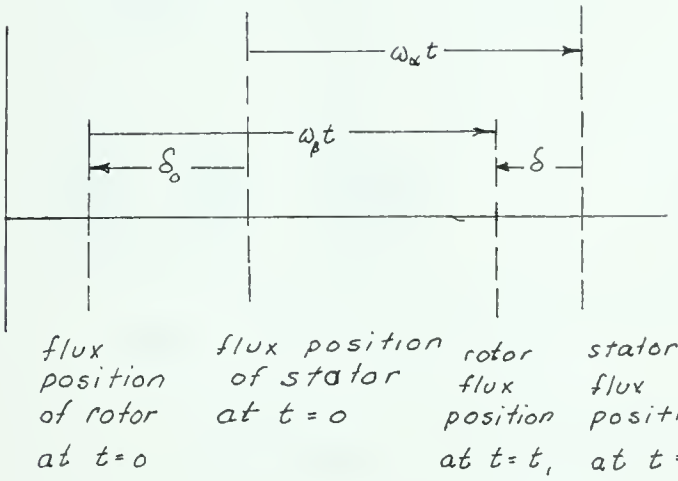


Fig 1 Flux Displacements with Locked Rotor

If δ_o is the physical displacement between the instantaneous stator flux phase "a" and the instantaneous rotor flux phase "a" at t=0, $\omega_\alpha t = 2\pi f_\alpha t$, $\omega_\beta t = 2\pi f_\beta t$ and δ is the physical displacement between the instantaneous stator flux phase "a" and the instantaneous rotor flux phase "a" at time t=t, then from Fig. 1

$$\omega_\beta t - \delta = \omega_\alpha t - \delta_o$$

or $$(\omega_\beta - \omega_\alpha) t + \delta_o = \delta$$

For obvious reasons, then, one deduces that

$$\phi = \delta = (\omega_\beta - \omega_\alpha) t + \delta_o$$

provided the rotor body does not rotate. In general, however, the rotor body rotates and consideration must be given to this fact. With reference to fig. 2 one uses the following notation:

δ_o is the "physical" displacement between instantaneous stator flux "a" and the instantaneous rotor flux phase "a" at t=0

$$\omega_\alpha t = 2\pi f_\alpha t \ , \quad \omega_\beta t = 2\pi f_\beta t$$

ϕ is the "electrical" displacement between instantaneous stator flux "a" and the instantaneous rotor flux phase "a" at $t=t_1$

and δ is the displacement of the rotor phase "a" in time t.

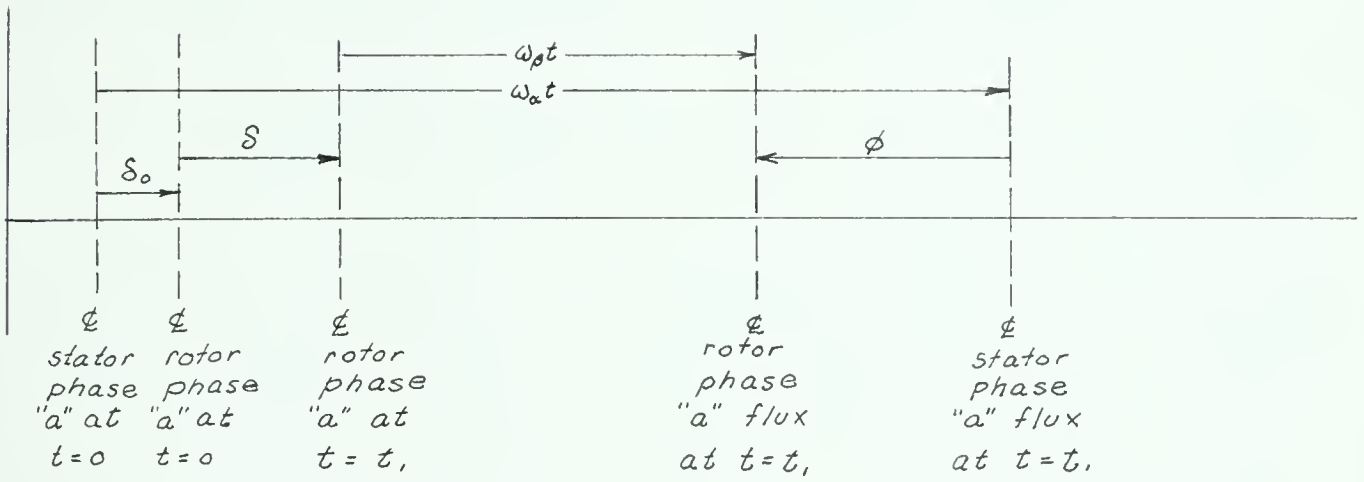


Fig. 2 Flux Displacements with Unlocked Rotor

From Fig. 2 one can deduce that

$$\delta_o + \delta + \omega_\beta t - \phi = \omega_\alpha t$$

or

$$(\omega_\beta - \omega_\alpha)\, t + (\delta_o + \delta) = \phi$$

Clearly $\delta_o + \delta$ can be replaced by δ if δ_o is assumed as a constant of integration. Then

$$\phi = 2\pi (f_\beta - f_\alpha)\, t + \delta \tag{4}$$

Differentiating equation (4) with respect to time gives

$$\dot{\phi} = \frac{d\phi}{dt} = 2\pi (f_\beta - f_\alpha) + \frac{d\delta}{dt} \tag{5}$$

Thus:

$$\omega_t = \frac{d\delta}{dt} = \sum_{i=1}^{n} \frac{\Delta t}{J} \left(T_{A_i} - R\,\omega_{i-1} \right) \tag{2}$$

$$\delta_t = \delta_o + \sum_{i=1}^{n} \Delta t \sum_{i=1}^{n} \frac{\Delta t}{J} \left(T_{A_i} - R\,\omega_{i-1} \right) \tag{3}$$

$$\phi_t = 2\pi (f_\beta - f_\alpha)\, t + \left\{ \delta_o + \sum_{i=1}^{n} \Delta t \sum_{i=1}^{n} \frac{\Delta t}{J} \left(T_{A_i} - R\,\omega_{i-1} \right) \right\} \tag{4}$$

$$\dot{\phi}_t = 2\pi (f_\beta - f_\alpha) + \sum_{i=1}^{n} \frac{\Delta t}{J} \left(T_{A_i} - R\,\omega_{i-1} \right) \tag{5}$$

CHAPTER IV

DAMPING FUNCTIONS AND POLAR MOMENTS OF INERTIA

I. DAMPING FUNCTIONS

Ideally friction and windage would consume no power and require no torque. In actual fact, friction and windage give rise to damping functions. Since these damping functions are important to the whole study, the damping functions are studied.

Frictional forces do not occur until motion is on the verge of occurring or actually occurs. At such time, as motion occurs the frictional forces suddenly occur and these frictional forces are finite. Clearly, however, the rate of change of the forces with respect to time is not defined, and neither is the rate of change of the forces with respect to speed.

Since no power is consumed until motion actually occurs one can assume the following:

(a) After motion actually occurs, the component of friction, windage and viscosity power loss that is linearly dependent on speed must be purely frictional.

(b) After motion actually occurs, the component of friction, windage and viscosity power loss that is dependent on the square of speed should be composed of windage and viscosity.

Clearly the total power consumed in friction, windage and viscosity should be continuous except at the origin (0 speed, 0 power), and

all of its derivatives should be continuous.

Mathematicians have shown that any continuous function can be expanded in a power series. Such proofs are found in most textbooks of advanced calculus. If the assumption is made that friction and windage power is continuous with respect to speed then

$$P_{F+W} = \sum_{n=0}^{n=\infty} P_n S^n \tag{1}$$

However

$$P_{F+W} = 0 \quad at \quad S = 0 \tag{1A}$$

Consequently

$$P_0 = 0$$

Hence

$$P_{F+W} = \sum_{n=1}^{\infty} P_n S^n$$

Ordinarily the series in equation (1A) converge very quickly and one can forget terms such as $P_3 S^3$.

Referring to Equation (1) Chapter III, $R\omega$ must have the dimensions of torque and hence R must have the dimensions of torque seconds per radian. Equation (1A) above can be modified as follows:

$$\frac{P_{F+W}}{S} = T_{F+W} = \sum_{n=1}^{\infty} P_n S^{n-1} \tag{2}$$

Also $R\omega$ can be modified as

$$R\omega = R \frac{2\pi S}{60}$$

From (2) one can readily deduce that

$$\frac{2\pi S}{60} R = P_2 S$$

or

$$R = \frac{60 P_2}{2\pi} \tag{3}$$

If the friction and windage losses can be determined at a reasonable number of speeds and if a quadratic regression can be applied, then R can be determined from such a technique. The writer attempted such a series of measurements and the technique employed is outlined in Section III of this paper.

II. POLAR MOMENTS OF INERTIA

The angular kinetic energy work theorem states that the kinetic energy possessed by a body rotating at ω radians per second is $\frac{1}{2} J\omega^2$ ft-lbs$_\omega$, where J is the polar moment of inertia. If all supply of power to such a rotating device is removed, then the rotor will be retarded by friction windage and viscosity.

Hence

$$\frac{1}{2} J\omega^2 = \int_0^t \sum_{n=1}^{n=\infty} P_n s^n \, d\tau$$

$$= \sum_{n=1}^{\infty} \int_0^t P_n s^n \, d\tau \qquad (4A)$$

Presumably equation (1A) Section I has enabled one to plot the locus of friction, windage and viscosity power. Then the area between the axis of speed and the locus of friction, windage and viscosity power is $\int_0^t \sum_{n=1}^{n=\infty} P_n s^n \, ds$. This last statement is intended to demonstrate the complexity of the problem since the increments of integration do not agree and since $S = \frac{d\delta}{dt}$, $S^2 = \left(\frac{d\delta}{dt}\right)^2$

Unfortunately S is a function of time, and such terms as $\int_0^t P_2 \left(\frac{d\delta}{dt}\right)^2 dt$ cannot be defined analytically. Neglecting such terms

would be tantamount to assuming that no damping torques exist. Clearly other approaches are necessary.

III. RETARDATION TECHNIQUE FOR DETERMINING POLAR MOMENTS OF INERTIA

If one applies the differential equation

$$J\dot{\omega} + R\omega = 0 \tag{4}$$

one, in effect, assumes that no purely frictional torques exist since R is windage and viscosity dependent. Appendix C contains several figures which indicate that purely frictional torques do exist. The retardation technique, which is the standard technique, assumes differential equation (4) to be correct.

If the body is rotating at rate ω_o radians per second when all supply of power fails then the solution to equation (4) is as follows

$$\omega = \omega_o e^{-Rt/J} \tag{5}$$

If more moment of inertia is added to the revolving body the following complications arise:

(a) The frictional force in the bearings increases because of the increased bearing pressure.

(b) The windage force increases because an increased area is added to come in contact with air.

(c) The viscosity effects in the bearings are unknown for the following reasons:

(1) The oil films become smaller and shearing forces in the oil films become more dependent on actual bearing temperature.

(2) The thickness of the oil films govern, to some extent, the coefficient of viscosity of the oil.

(3) With very thin oil films the probability of metal to metal contact is increased.

(d) The center of gravity of the shaft moves axially and results in non-equal bearing pressures and consequent increase in the probability of metal to metal contact.

Clearly some dubious assumptions are involved in use of the Retardation Technique since the effects (a), (b), (c) and (d) are neglected. Assuming, also, that the purely frictional effects are negligible one can repeat the experiment with a moment of inertia increased to J'. If ω_o is the same starting speed and ω' the new speed at time t,

$$\omega' = \omega_o e^{-Rt/J'} \tag{6}$$

From equation (5) and equation (6) one may deduce that

$$\frac{J}{J'} = \frac{\ln \frac{\omega_o}{\omega'}}{\ln \frac{\omega_o}{\omega}} \quad \text{or that} \quad J = \Delta J \frac{\ln \frac{\omega_o}{\omega'}}{\ln \frac{\omega'}{\omega}} \tag{7}$$

where: ω_o is the speed of the rotating body at the moment all supplies of power are removed.

ω' is the speed at time t with added inertia.

ω is the speed at time t without added inertia.

ΔJ is the added moment of inertia.

Similarly one may deduce that

$$R = \frac{1}{t} \ln \frac{\omega_o}{\omega} \quad \Delta J \quad \frac{\ln \frac{\omega_o}{\omega'}}{\ln \frac{\omega}{\omega'}} \tag{8}$$

Equation (4) can be modified to allow for a purely frictional torque as well as damping torques. If T_F is the constant frictional torque, the new differential equation is

$$J\dot{\omega} + R\omega + T_F = 0 \tag{9}$$

With the use of Laplace Transforms

$$J\dot{\omega} + R\omega + T_F = 0 \quad \text{becomes} \tag{9}$$

$$J\{s\omega(s) - \omega_o\} + R\omega(s) + \frac{T_F}{s} = 0$$

Thus

$$\omega(s) = \frac{J\omega_o}{J(s + \frac{R}{J})} - \frac{T_F/J}{s(s + \frac{R}{J})} \tag{10}$$

Using Inverse Laplace Transforms

$$\omega(t) = \omega_o e^{-Rt/J} - \frac{T_F}{R}(1 - e^{-Rt/J}) \tag{11}$$

If the moment of inertia can be increased without changing R or T_F then

$$\omega'(t) = \omega_o e^{-Rt/J'} - \frac{T_F}{R}(1 - e^{-Rt/J'}) \tag{12}$$

From equation (11)

$$\omega(t) + \frac{T_F}{R} = (\omega_o + \frac{T_F}{R}) e^{-Rt/J} \tag{13}$$

From equation (12)

$$\omega'(t) + \frac{T_F}{R} = (\omega_o + \frac{T_F}{R}) e^{-Rt/J'} \tag{14}$$

Rearranging equation (13)

$$\frac{Rt}{J} = \ln \left\{ \frac{\omega_o + \frac{T_F}{R}}{\omega(t) + \frac{T_F}{R}} \right\} \tag{13A}$$

or

$$\frac{J}{R} = \frac{t}{\ln\left\{\frac{\omega_o + \frac{T_F}{R}}{\omega(t) + \frac{T_F}{R}}\right\}} \tag{15}$$

Similarly equation (14) gives

$$\frac{J'}{R} = \frac{t}{\ln\left\{\frac{\omega_o + \frac{T_F}{R}}{\omega'(t) + \frac{T_F}{R}}\right\}} \tag{16}$$

Thus

$$\frac{J}{J'} = \frac{\ln\left\{\frac{\omega_o + \frac{T_F}{R}}{\omega'(t) + \frac{T_F}{R}}\right\}}{\ln\left\{\frac{\omega_o + \frac{T_F}{R}}{\omega(t) + \frac{T_F}{R}}\right\}} \tag{17}$$

Since $J' = J + \Delta J$ equation (17) is equivalent to

$$J = \Delta J \cdot \frac{\ln\left\{\frac{\omega_o + \frac{T_F}{R}}{\omega'(t) + T_F/R}\right\}}{\ln\left\{\frac{\omega'(t) + T_F/R}{\omega(t) + T_F/R}\right\}} \tag{18}$$

Substituting into equation (13A)

$$R = \frac{1}{t}\,\Delta J\,\frac{\ln\left\{\frac{\omega_o + T_F/R}{\omega'(t) + T_F/R}\right\}}{\ln\left\{\frac{\omega'(t) + T_F/R}{\omega(t) + T_F/R}\right\}} \cdot \ln\left\{\frac{\omega_o + T_F/R}{\omega(t) + T_F/R}\right\} \tag{18A}$$

where ω_o is the speed of the rotating mass when all power sources are disconnected

$\omega'(t)$ is the speed of the rotating mass when it is coupled to another rotating mass and the time is t seconds after all power sources are disconnected

$\omega(t)$ is the speed of the rotating mass, alone, t seconds after all power sources are disconnected.

Δt is the added moment of inertia

R is the constant damping function.

Ordinarily Friction forces and torques are unknown and R is distinctly unknown. Consequently the term T_F/R is unknown.

If a different ΔJ, say $\Delta J'$, is employed and the reasoning repeated then one must obtain the same value of J as in equation (18). Thus

$$J = \Delta J' \cdot \frac{\ln \frac{\omega_o + T_F/R}{\omega''(t) + T_F/R}}{\ln \frac{\omega''(t) + T_F/R}{\omega(t) + T_F/R}} \qquad (19)$$

where $\Delta J'$ is the new increase in moment of inertia

$\omega''(t)$ is the new speed at time t with the new increase in moment of inertia

$\omega(t)$ is the speed of the rotating mass at time t without any any increase in moment of inertia.

ω_o is the speed of the rotating mass the instant all power sources are removed.

Similarly

$$R = \frac{1}{t} \Delta J' \cdot \frac{\ln\left\{\frac{\omega_o + T_F/R}{\omega''(t) + T_F/R}\right\}}{\ln\left\{\frac{\omega''(t) + T_F/R}{\omega(t) + T_F/R}\right\}} \cdot \ln\left\{\frac{\omega_o + T_F/R}{\omega(t) + T_F/R}\right\} \qquad (19A)$$

$$= \frac{1}{t} \Delta J \cdot \frac{\ln\left\{\frac{\omega_o + T_F/R}{\omega^*(t) + T_F/R}\right\}}{\ln\left\{\frac{\omega^*(t) + T_F/R}{\omega(t) + T_F/R}\right\}} \cdot \ln\left\{\frac{\omega_o + T_F/R}{\omega(t) + T_F/R}\right\} \qquad (18A)$$

Clearly an iterative procedure could solve equations (18A) and (19A) for T_f/R and R could be calculated from either equation.

Summary:

(1) The standard technique for determining the polar moment of inertia tends to indicate a polar moment of inertia which is less than the actual value because it neglects the purely frictional torques.

(2) Modifications which allow for pure friction torques result in formulae which require iterative procedures for their solution.

The writer's technique for determining the polar moment of inertia does not give the accuracy of the retardation technique but it does have the advantage that it may be built in-situo from scrap material and for most practical purposes the accuracy is sufficient. This technique is outlined in Section IV of this chapter.

Since the polar moment of inertia and damping figure so prominently in the mechanical equations of motion a detailed study of friction, windage, viscosity and the polar moment of inertia was undertaken.

IV. FRICTION BY MODIFIED SUPPLY OF LOSSES TECHNIQUE

The wound rotor machine studied was normally coupled to a compound-wound direct current machine, the armature and all field connections of which were separately accessible. The shunt field of the direct current machine was separately excited from a constant current supply while the series fields were unused.

Combined armature brush and copper loss was determined at ambient temperature. Since armature currents during the test were low no temperature corrections were applied.

For several values of decreasing speed, speed, current and armature terminal voltage were recorded as in the conventional "Efficiency by Supply of Losses" Method, this being done for the case when the wound rotor was coupled to the direct current machine. When the rotor stalled the wound rotor induction machine was uncoupled and the mechanical losses of the direct current machine were used as the load for the direct current machine.

The gross power, P_T , applied to the terminals of the armature of the direct current machine is composed of the following terms:

(a) P_H , the hysteresis power loss in the armature, which is proportional to $\phi^{1.6} n$ where ϕ is the flux in the armature and n is the velocity of the armature.

(b) P_E , the eddy current power loss in the armature,

which is proportional to n^2.

(c) P_R , the resistance power loss in the armature, which depends on the brush and copper resistance and the square of the armature current.

(d) P_{F+W} , the total friction and windage power loss of the armature.

If one could keep the armature current sufficiently small then the armature flux would be independent of armature current. If one could assume that radiation is the chief manner in which the armature is cooled then the value of P_R would be independent of speed. If one could assume that friction and windage dominate viscosity forces then one could and would assume that P_{F+W} is independent of temperature. Unfortunately none of these assumptions is valid but all of these assumptions are necessary for the analysis to follow.

If the subscript A is used to denote a study when the wound rotor is coupled to the direct current machine, and subscript B is used to denote that only the direct current machine is running, then

$$P_{H_A} + P_{E_A} + P_{R_A} + P_{F+W_A} = P_{T_A}$$

or

$$P_{H_A} + P_{E_A} + P_{F+W_A} = P_{T_A} - P_{R_A} \qquad (1)$$

Similarly

$$P_{H_B} + P_{E_B} + P_{R_B} + P_{F+W_B} = P_{T_B}$$

or

$$P_{H_B} + P_{E_B} + P_{F+W_B} = P_{T_B} - P_{R_B} \qquad (2)$$

Subtracting equation (2) from equation (1)

$$(P_{H_A} + P_{E_A}) - (P_{H_B} + P_{E_B}) + (P_{F+W_A} - P_{F+W_B}) = (P_{T_A} - P_{R_A}) - (P_{T_B} - P_{R_B}) \quad (3)$$

Now all terms on the left hand side of equation (3) are flux and/or speed dependent. If the independent variable is speed and the flux is constant certain terms in equation (3) cancel and thus the friction and windage power in the alternating current machine must be given by

$$P_{F+W_{I.M.}} = (P_{F+W_A} - P_{F+W_B}) = (P_{T_A} - P_{R_A}) - (P_{T_B} - P_{R_B}) \quad (4)$$

The exact procedure involved will be fairly obvious from a study of the several figures in Appendix C.

V. MECHANICAL MEASUREMENT OF MECHANICAL DAMPING

The results obtained by the technique of Section IV were not completely reliable because there seemed to be no way of reproducing them at later dates. Consequently this writer felt that an attempt should be made to determine, mechanically, the mechanical damping and polar moment of inertia.

This technique involved wrapping aluminum wire around a shaft, passing it over a pulley and applying a large weight on the other end of the wire.

The technique necessitated the assumptions as follows:

(a) The pulley had zero moment of inertia

(b) The wire was weightless

(c) The wire was inextensible.

If W is the applied force and r is the shaft mean radius, then Wr is the applied torque. However a purely frictional torque can be deduced from fig. 4 Appendix C and deducted from Wr.

Unfortunately the solution of the differential equation, which describes the motion of the weight, is cumbersome and involves the solution of a transcendental equation.

The application of Newton's Third Law gives

$$J\dot{\omega} + R\omega = W'r$$

Applying Laplace Transforms to equation (1) gives

$$J(s^2\theta_s - s\theta_0 - \dot{\theta}_0) + R(s\theta_s - \theta_0) = \frac{W'r}{s}$$

Therefore

$$\theta_s = \frac{W'r}{Js^2(s+\frac{R}{J})} + \frac{\theta_0}{s} + \frac{\dot{\theta}_0}{s(s+\frac{R}{J})} \qquad (2)$$

If t_1 represents the time when the weight reaches minimum altitude the Inverse Laplace Transform of (2) gives

$$\theta_t = \frac{W'r}{J}\int_0^{t_1}\int_0^{\tau} e^{-\frac{R\lambda}{J}}\,d\lambda\,d\tau + \theta_0 + \dot{\theta}_0\int_0^{t_1} e^{-\frac{R\lambda}{J}}\,d\lambda$$

$$= \frac{W'r}{J}\int_0^{t_1}\left\{-\frac{J}{R}\right\}e^{-\frac{R\lambda}{J}}\Big|_0^{\tau}\,d\tau + \theta_0 + \dot{\theta}_0\left\{-\frac{J}{R}\right\}e^{-\frac{R\lambda}{J}}\Big|_0^{t_1}$$

$$= \frac{W'r}{J}\times\frac{J}{R}\int_0^{t_1}(1-e^{-\frac{R\tau}{J}})\,d\tau + \theta_0 + \dot{\theta}_0\left\{1-e^{-\frac{Rt}{J}}\right\}\frac{J}{R}$$

$$= \frac{W'r}{R}\left\{\tau + e^{-\frac{R\tau}{J}}\frac{J}{R}\right\}\Big|_0^{t_1} + \theta_0 + \dot{\theta}_0\left\{1-e^{-\frac{Rt_1}{J}}\right\}\frac{J}{R}$$

$$= \frac{w'r}{R}\left\{ t_1 - \frac{J}{R}\left(1 - e^{-\frac{Rt}{J}}\right)\right\} + \theta_0 + \dot{\theta}_0 \frac{J}{R}\left\{1 - e^{-\frac{Rt_1}{J}}\right\}$$

$$\dot{\theta}_t = \frac{w'r}{R}\left\{1 - e^{-\frac{Rt_1}{J}}\right\} + \dot{\theta}_0 e^{-\frac{Rt}{J}}$$

If the weight starts, at height h_1, from rest and proceeds downwards, $\theta_t = \frac{h}{r}$ where h is the distance the weight drops and r is the mean radius. Thus

$$h = \frac{w'r^2}{R}\left\{ t_1 - \frac{J}{R}\left(1 - e^{-Rt_1/J}\right)\right\} + r\theta_0 + r\dot{\theta}_0 \frac{J}{R}\left\{1 - e^{-Rt/J}\right\}$$

but

$$\theta_0 = 0 \quad \text{and} \quad \dot{\theta}_0 = 0$$

then

$$h = \frac{w'r^2}{R}\left\{ t_1 - \frac{J}{R}\left(1 - e^{-\frac{Rt_1}{J}}\right)\right\} \tag{3}$$

$$\dot{h} = \frac{w'r^2}{R}\left\{1 - e^{-\frac{Rt_1}{J}}\right\} \tag{4}$$

After the weight reaches its minimum altitude the applied torque on the shaft reverses. The velocity at minimum altitude is given by equation (4) and the value of $r\theta_0$ is given by equation (3).

Thus

$$h' = -\frac{w'r^2}{R}\left\{ t_1' - \frac{J}{R}\left(1 - e^{-\frac{Rt_1'}{J}}\right)\right\} + \frac{w'r^2}{R}\left\{ t_1 - \frac{J}{R}\left(1 - e^{-\frac{Rt_1}{J}}\right)\right\}$$
$$+ \frac{w'r^2}{R}\left\{1 - e^{-\frac{Rt_1}{J}}\right\}\frac{J}{R}\left\{1 - e^{-\frac{Rt_1}{J}}\right\} \tag{5}$$

$$\dot{h}' = -\frac{w'r^2}{R}\left\{1 - e^{-\frac{Rt_1'}{J}}\right\} + \frac{w'r^2}{R}\left\{1 - e^{-\frac{Rt_1}{J}}\right\} e^{-\frac{Rt_1'}{J}} \tag{6}$$

When the weight reaches its maximum height,

thus

$$\frac{w'r^2}{R}\left\{1 - e^{-\frac{Rt_1'}{J}}\right\} = \frac{w'r^2}{R}\left\{1 - e^{-\frac{Rt_1}{J}}\right\} e^{-\frac{Rt_1'}{J}} \tag{7}$$

Resubstituting for $\left(1 - e^{-Rt_1/J}\right)$ in equation (5) reveals that:

$$h'_m = -\frac{w'r^2}{R}\left\{t_1' - \frac{J}{R}\left(1-e^{-\frac{Rt_1}{J}}\right)e^{-\frac{Rt_1'}{J}}\right\} + \frac{w'r^2}{R}\left\{t_1 - \frac{J}{R}\left(1-e^{-\frac{Rt_1}{J}}\right)\right\}$$
$$+ \frac{w'r^2}{R}\left\{1-e^{-\frac{Rt_1}{J}}\right\}\frac{J}{R}\left\{1-e^{-\frac{Rt_1}{J}}\right\}e^{-\frac{Rt_1'}{J}}$$

$$= \frac{w'r^2}{R}(t_1 - t_1') - \frac{w'r^2}{R^2}J\left(1-e^{-\frac{Rt_1}{J}}\right)\left(1-e^{-\frac{Rt_1'}{J}}\right)$$
$$+ \frac{w'r^2J}{R^2}e^{-\frac{Rt_1'}{J}}\left\{1-e^{-\frac{Rt_1}{J}}\right\}\left\{1-e^{-\frac{Rt_1}{J}}\right\}$$

$$= \frac{w'r^2}{R}(t_1 - t_1') - \frac{w'r^2J}{R^2}\left(1-e^{-\frac{Rt_1}{J}}\right)\left(1-e^{-\frac{Rt_1'}{J}}\right)$$
$$+ \frac{w'r^2J}{R^2}\left\{1-e^{-\frac{Rt_1}{J}}\right\}\left\{1-e^{-\frac{Rt_1'}{J}}\right\}$$

$$= \frac{w'r^2(t_1 - t_1')}{R} \qquad (9)$$

While equation (9) appears to be very interesting it is of little use since t_1, and t_1', are unknown quantities. Furthermore, there does not seem to be any method to determine t_1, and t_1', even though $\tau = t_1 + t_1'$ can be measured and h and h' can be measured. The only truly satisfactory procedure would be to measure t_1 and t_1' separately. This could be done with two photo-electric cells. If so done the damping function R could be determined to very great precision. Then substitution of R into equation (3) would determine J in terms of a transcendental equation.

Clearly an iterative procedure is involved in the above solution but if the same care is employed as in the retardation technique, excellent accuracy would be expected.

In order to achieve a solution to the problem, the differential equation was assumed to be $J\dot{\omega} + R\omega = -\int_0^{\tau} w'r\,\omega\,dt$

which has the solution

$$\theta = A e^{-\frac{Rt}{2J}} \cos t\sqrt{\left(\frac{wr}{J} - \left(\frac{R}{2J}\right)^2\right)}$$

the period of which is

$$\tau = \frac{2\pi}{\sqrt{\left\{\frac{wr}{J} - \left(\frac{R}{2J}\right)^2\right\}}}$$

The nature of the errors in the above approximation is unknown and cannot be predicted.

A very quick method for determining the moment of inertia has been demonstrated and formulae have been derived to indicate possible improvements.

Appendix C explains the procedure employed to obtain the polar moment of inertia.

VI. MOMENT OF INERTIA BY ELECTRICAL MEANS

If the direct current machine with constant field current is used to accelerate the rotor of the alternating current machine then theory indicates as follows:

$$\frac{1}{2} J \left(\dot{\theta}^2 - \dot{\theta}_o^2 \right) = \int_o^t v i \, dt - \int_o^t P_H \, dt - \int_o^t P_E \, dt - \int_o^t P_{F+w} \, dt - \int_o^t P_R \, dt$$

where

$\dot{\theta}$ is the angular velocity at time t

$\dot{\theta}_o$ is the angular velocity at time t = 0

v is the armature terminal voltage

P_H, P_E, P_{F+w}, P_R are as defined in Section IV.

Clearly P_{F+w} and P_R are reasonably well known. However,

P_H and P_E are not known and one requires a "Separation of Losses" method to determine them.

In order to ascertain whether or not the idea might be fruitful, several attempts were made to correlate armature terminal voltage with speed. No correlation could be found and the attempts to measure P_H and P_E were not made.

Several factors explain the failure to obtain useful results from this method:

(a) Armature reaction reduces the generated back voltage.

(b) Hysteresis and eddy current power are dependent upon flux density and speed and the generated back voltage is, therefore, partly dependent on these quantities.

(c) Self-inductances in the shunt field prevent the reestablishment of shunt field flux.

This method could be improved by using a cathode ray oscilloscope equipped with an electronic switch to display instantaneous speed from a tachometer generator.

TABLE I
DERIVATIONS OF FORMULAE

1. $V_{\alpha 1}\epsilon^{j\omega_\alpha t} = i_{\alpha 1} r_\alpha + L_\alpha \frac{di_{\alpha 1}}{dt} + m\frac{d}{dt}(i_{\beta 1}\epsilon^{j\phi})$

$$\therefore \frac{di_{\alpha 1}}{dt} = \frac{1}{L_\alpha}\left\{ V_{\alpha 1}\epsilon^{j\omega_\alpha t} - i_{\alpha 1} r_\alpha - jm i_{\beta 1}\phi\epsilon^{j\phi} - m\epsilon^{j\phi}\left(\frac{d}{dt} i_{\beta 1}\right)\right\} \quad \text{--- (1A)}$$

2. $V_{\beta 1}\epsilon^{j\omega_\beta t} = i_{\beta 1} r_\beta + L_\beta \frac{di_{\beta 1}}{dt} + m\frac{d}{dt}(i_{\alpha 1}\epsilon^{-j\phi})$

$$\therefore \frac{di_{\beta 1}}{dt} = \frac{1}{L_\beta}\left\{ V_{\beta 1}\epsilon^{j\omega_\beta t} - i_{\beta 1} r_\beta + jm\phi\epsilon^{-j\phi} i_{\alpha 1} - m\epsilon^{-j\phi}\left(\frac{di_{\alpha 1}}{dt}\right)\right\} \quad \text{--- (2A)}$$

SUBSTITUTE (2A) INTO (1A)

$$\frac{di_{\alpha 1}}{dt} = \frac{1}{L_\alpha\left\{1 - \frac{m^2}{L_\alpha L_\beta}\right\}}\left\{ V_{\alpha 1}\epsilon^{j\omega_\alpha t} - i_{\alpha 1} r_\alpha - jm\phi i_{\beta 1}\epsilon^{j\phi} - \frac{m V_{\beta 1}}{L_\beta}\epsilon^{j(\omega_\beta t+\phi)} + \frac{m r_\beta}{L_\beta} i_{\beta 1}\epsilon^{j\phi} - j\frac{m^2}{L_\beta}\phi i_{\alpha 1}\right\} \quad \text{---- (1B)}$$

SUBSTITUTE (1A) INTO (2A)

$$\frac{di_{\beta 1}}{dt} = \frac{1}{L_\beta\left\{1 - \frac{m^2}{L_\alpha L_\beta}\right\}}\left\{ V_{\beta 1}\epsilon^{j\omega_\beta t} - i_{\beta 1} r_\beta + jm i_{\alpha 1}\phi\epsilon^{-j\phi} - \frac{m}{L_\alpha} V_{\alpha 1}\epsilon^{j(\omega_\alpha t-\phi)} + \frac{m}{L_\alpha} i_{\alpha 1} r_\alpha\epsilon^{-j\phi} + j\frac{m^2}{L_\alpha}\phi i_{\beta 1}\right\} \quad \text{--- (2B)}$$

3. $V_{\alpha 2}\epsilon^{-j\omega_\alpha t} = i_{\alpha 2} r_\alpha + L_\alpha \frac{di_{\alpha 2}}{dt} + m\frac{d}{dt}(i_{\beta 2}\epsilon^{-j\phi})$

$$\therefore \frac{di_{\alpha 2}}{dt} = \frac{1}{L_\alpha}\left\{ V_{\alpha 2}\epsilon^{-j\omega_\alpha t} - i_{\alpha 2} r_\alpha + jm\phi i_{\beta 2}\epsilon^{-j\phi} - m\epsilon^{-j\phi}\left(\frac{di_{\beta 2}}{dt}\right)\right\} \quad \text{-- (3A)}$$

4. $V_{\beta 2}\epsilon^{-j\omega_\beta t} = i_{\beta 2} r_\beta + L_\beta \frac{di_{\beta 2}}{dt} + m\frac{d}{dt}(i_{\alpha 2}\epsilon^{j\phi})$ ---- (4A)

SUBSTITUTE (4A) INTO (3A)

$$\frac{di_{\alpha 2}}{dt} = \frac{1}{L_\alpha\left\{1 - \frac{m^2}{L_\alpha L_\beta}\right\}}\left\{ V_{\alpha 2}\epsilon^{-j\omega_\alpha t} - i_{\alpha 2} r_\alpha + jm\phi i_{\beta 2}\epsilon^{-j\phi} - \frac{m V_{\beta 2}}{L_\beta}\epsilon^{-j(\omega_\beta t+\phi)} + \frac{m r_\beta}{L_\beta} i_{\beta 2}\epsilon^{-j\phi} + j\frac{m^2}{L_\beta}\phi i_{\alpha 2}\right\} \quad \text{---- (4B)}$$

SUBSTITUTE (3A) INTO (4A)

$$\frac{di_{\beta 2}}{dt} = \frac{1}{L_\beta\left\{1 - \frac{m^2}{L_\alpha L_\beta}\right\}}\left\{ V_{\beta 2}\epsilon^{-j\omega_\beta t} - i_{\beta 2} r_\beta - jm\phi\epsilon^{j\phi} i_{\alpha 2} - \frac{m}{L_\alpha} V_{\alpha 2}\epsilon^{-j(\omega_\alpha t-\phi)} + \frac{m}{L_\alpha} r_\alpha i_{\alpha 2}\epsilon^{j\phi} - j\frac{m^2}{L_\alpha}\phi i_{\beta 2}\right\} \quad \text{---- (4C)}$$

$$\omega_t = \sum_{i=1}^{n} \frac{\Delta t}{J}\left(T_{A_i} - R\omega_{i-1}\right)^{*} \; ; \quad \delta_t = \sum_{i=1}^{n}\Delta t \sum_{i=1}^{n}\frac{\Delta t}{J}\left(T_{A_i} - R\omega_{i-1}\right)^{*}$$

$$\phi = 2\pi\left(f_\beta - f_\alpha\right)t + \sum_{i=1}^{n}\Delta t\sum_{i=1}^{n}\frac{\Delta t}{J}\left(T_{A_i} - R\omega_{i-1}\right)^{*}$$

$$\phi = 2\pi\left(f_\beta - f_\alpha\right)t + \sum\frac{\Delta T}{J}\left(T_{A_i} - R\omega_{i-1}\right)^{*}$$

* REFER TO CHAPTER III

CHAPTER V

METHOD OF SOLUTION AND CONCLUSIONS

I. METHOD

Rough estimates indicate that a time increment of one millisecond would be too large and thus a large volume of computer output would be expected. The choice of digital computer, LGP 30, was unfortunate in several respects: firstly the outputting devices for this computer are very slow; secondly fixed point programming was necessary in order to gain internal speed of the computer; thirdly fixed point programming restricts the range of variables and finally errors are more frequently inserted in fixed point programming. The other digital computer, IBM 1620, had a heavy work load and was virtually unavailable to this writer. Since fixed point programming was necessary, a detailed knowledge of the parameters was necessary before programming could be attempted.

The transient currents, rotor accelerations, rotor velocities and rotor displacements are considered from the moment two systems, at slightly different frequencies, are paralleled through the machine. The same phenomena are studied when both systems experience a line-to-line fault, at the machine, at the moment of paralleling. In both cases it was assumed that stator currents had achieved steady state before paralleling the rotor circuit. Stator and rotor frequencies were 376.991119 and 350.000 electrical radians per second, respectively, initial rotor velocity and displacement were 0.00 electrical radians per second and 0.0192 electrical radians respectively.

FIG 1

LOCUS OF STATOR CURRENT

(POSITIVE SEQUENCE, NO FAULT)

$r_\alpha = 0.383\ \Omega$ $r_\beta = 0.0620\ \Omega$

$L_\alpha = 0.003371\ h$ $L_\beta = 0.0005199\ h$

$f_\beta = 350\ r/s$ $f_\alpha = 376.991119\ r/s$

$V_\alpha = 128\ v$ $V_\beta = 85.5\ v$

$\phi_0 = 0.0192\ T$ $m = 0.04955\ h$

$i_{\alpha 1_0} = 0.123 - j\,6.42\ a$ $i_{\alpha 2_0} = i_{\beta 1_0} = i_{\beta 2_0} = 0$

$J = 0.223$ $R = 0.149$

IMAGINARY AMPS

REAL AMPS

$T_1 = 0.0166\ sec$

$T_2 = 0.0333\ sec.$

$T_3 = 0.0500\ sec.$

$T_4 = 0.0666\ sec.$

DIRECTION OF INCREASING TIME

38A

FIG 2

LOCUS OF ROTOR CURRENT
POSITIVE SEQUENCE, NO FAULT

r_α = 0·383 Ω r_β = 0·062 Ω

L_α = 0·003371 h L_β = 0·0005199 h

f_α = 376·991119 r/s f_β = 350 r/s

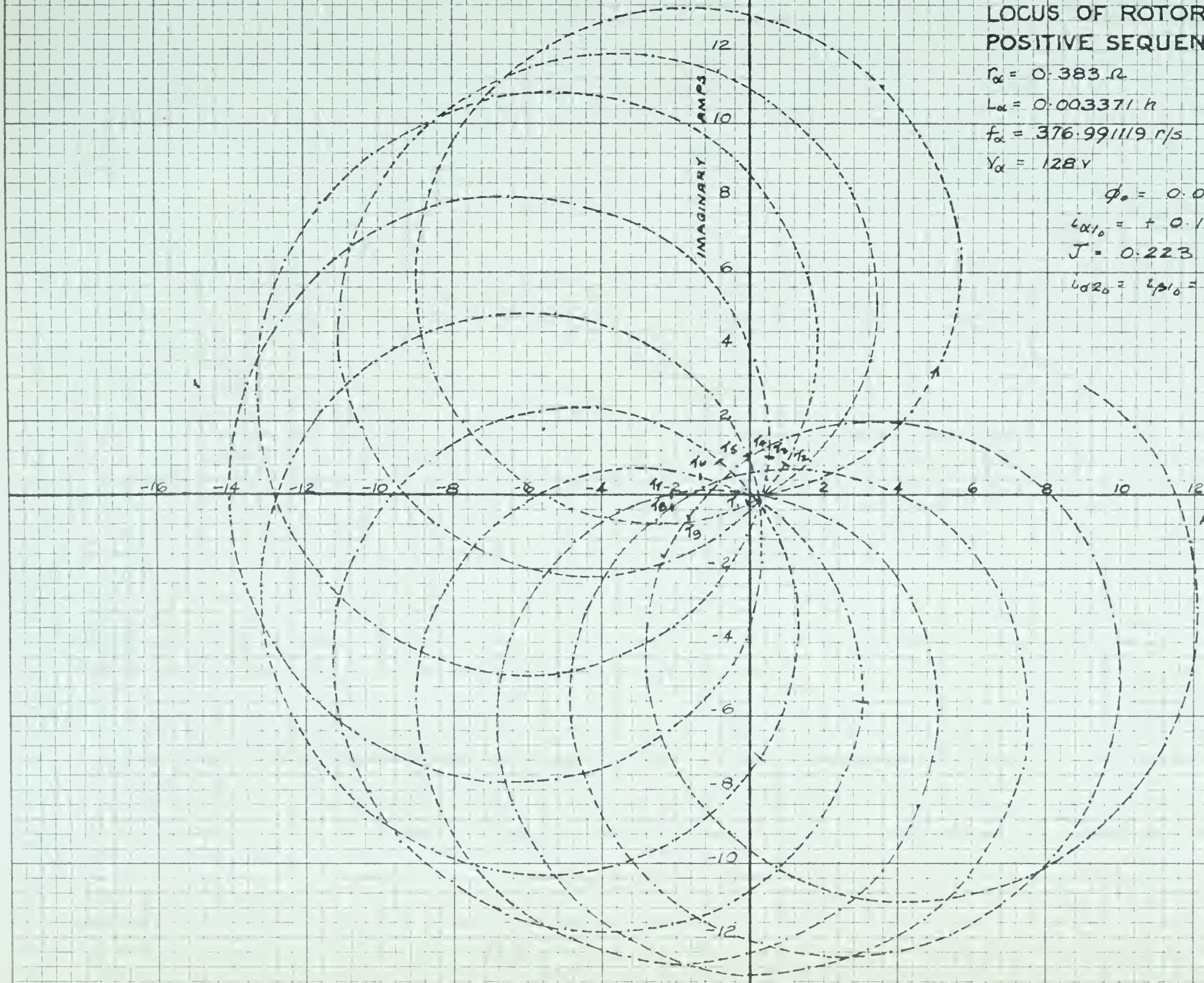
V_α = 128 V V_β = 85·5 V

ϕ_0 = 0·0192 r m = 0·04955 h

$i_{\alpha 1_0}$ = + 0·123 - j 6·42 a

J = 0·223 R = 0·149.

$i_{\alpha 2_0} = i_{\beta 1_0} = i_{\beta 2_0} = 0$



T_1 = 0.0166 sec

T_2 = 0.0333 sec

T_3 = 0.0500 sec.

T_4 = 0.0666 sec.

T_5 = 0.0833 sec.

T_6 = 0.1000 sec.

T_7 = 0.1166 sec.

T_8 = 0.1333 sec.

T_9 = 0.1500 sec.

FIG. 3

ACCELERATION ~ NO FAULT

$r_\alpha = 0.383\ \Omega$ $r_\beta = 0.062\ \Omega$

$L_\alpha = 0.003371\ h$ $L_\beta = 0.0005199\ h$

$f_\alpha = 376.991119\ r/s$ $f_\beta = 350\ r/s$

$V_\alpha = 128\ v$ $V_\beta = 85.5\ v$

$\phi_0 = 0.0192\ r$ $m = 0.04955\ h$

$L_{\alpha 1_0} = 0.123 - j\,6.428^\circ$ $J = 0.223$ $R = 0.149$

$L_{\alpha 2_0} = 0$ $L_{\beta 1_0} = L_{\beta 2_0} = 0.$

RADIANS/SEC²

400

200

0

-200

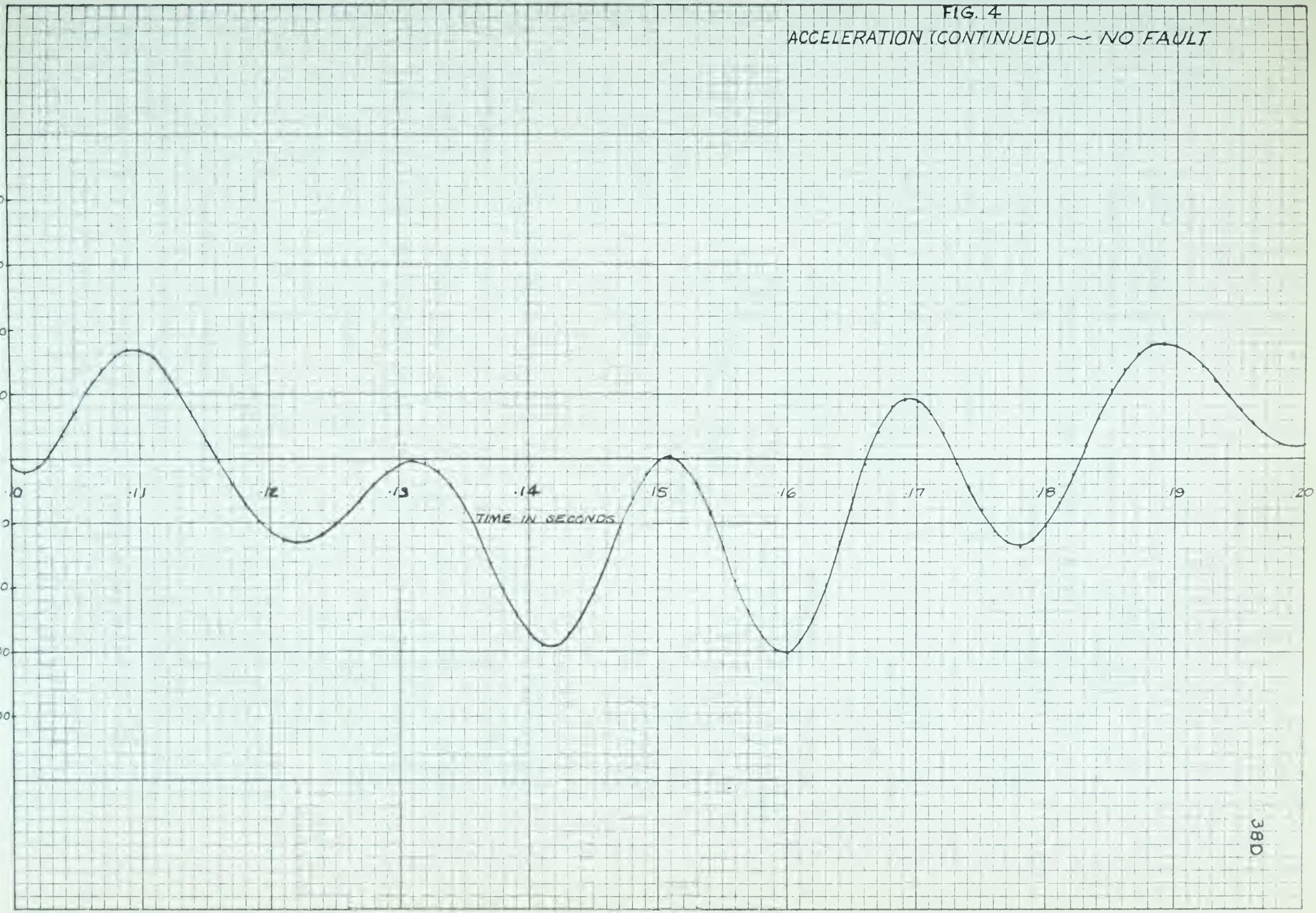
-400

:01 :02 :03 :04 :05 :06 :07 :08 :09 :10

TIME IN SECONDS

FIG. 4

ACCELERATION (CONTINUED) ~ NO FAULT



The writer attempted to program the solution directly from the differential equations found in Chapters I, II and III. The results of such a program were most disappointing. These equations were then rearranged as in Table I of this chapter and a new program was written. This program produced suitable results.

The time increment used was 0.2 milliseconds. This time increment appears to be almost optimal and should not be changed.

Fig. 1 displays the typical counter-clockwise motion with increasing time and therefore the locus is that of a positive sequence function. The locus is almost hypocycloidal in nature and displays marked periodicity in both phase and magnitude. The peak magnitude is approximately 6.5 amperes. The locus is of the positive sequence stator current.

Fig. 2 displays the typical counter-clockwise motion with increasing time and therefore the locus is that of a positive sequence function. As in Fig. 1 the locus is almost hypocycloidal and displays marked periodicity in both phase and magnitude. The peak magnitude is approximately 13.5 amperes. The locus is of the positive sequence rotor current.

Figures 3 and 4 display the rotor angular accelerations in electrical radians per second per second. The accelerations are periodic in nature passing through the time axis at roughly 0.0166, 0.0330, 0.050, 0.0666, 0.0833, 0.0995, 0.1160 etc. seconds. These

FIG 5

VELOCITY ~ NO FAULT

$r_\alpha = 0.383\,\Omega$ $r_\beta = 0.062\,\Omega$

$L_\alpha = 0.003371\,h$ $L_\beta = 0.000519\,9\,h$

$f_\alpha = 376.991\,19\ r/s$ $f_\beta = 350\ r/s$

$V_\alpha = 128\,v$ $V_\beta = 85.5\,v$

$\phi_0 = 0.0192\,r$ $m = 0.04955\,h$

$i_{\alpha 1_0} = 0.123 - j\,6.42\,a$ $J = 0.223$ $R = 0.149$

$i_{\alpha 2_0} = i_{\beta 1_0} = i_{\beta 2_0} = 0$

RADIANS/SEC.

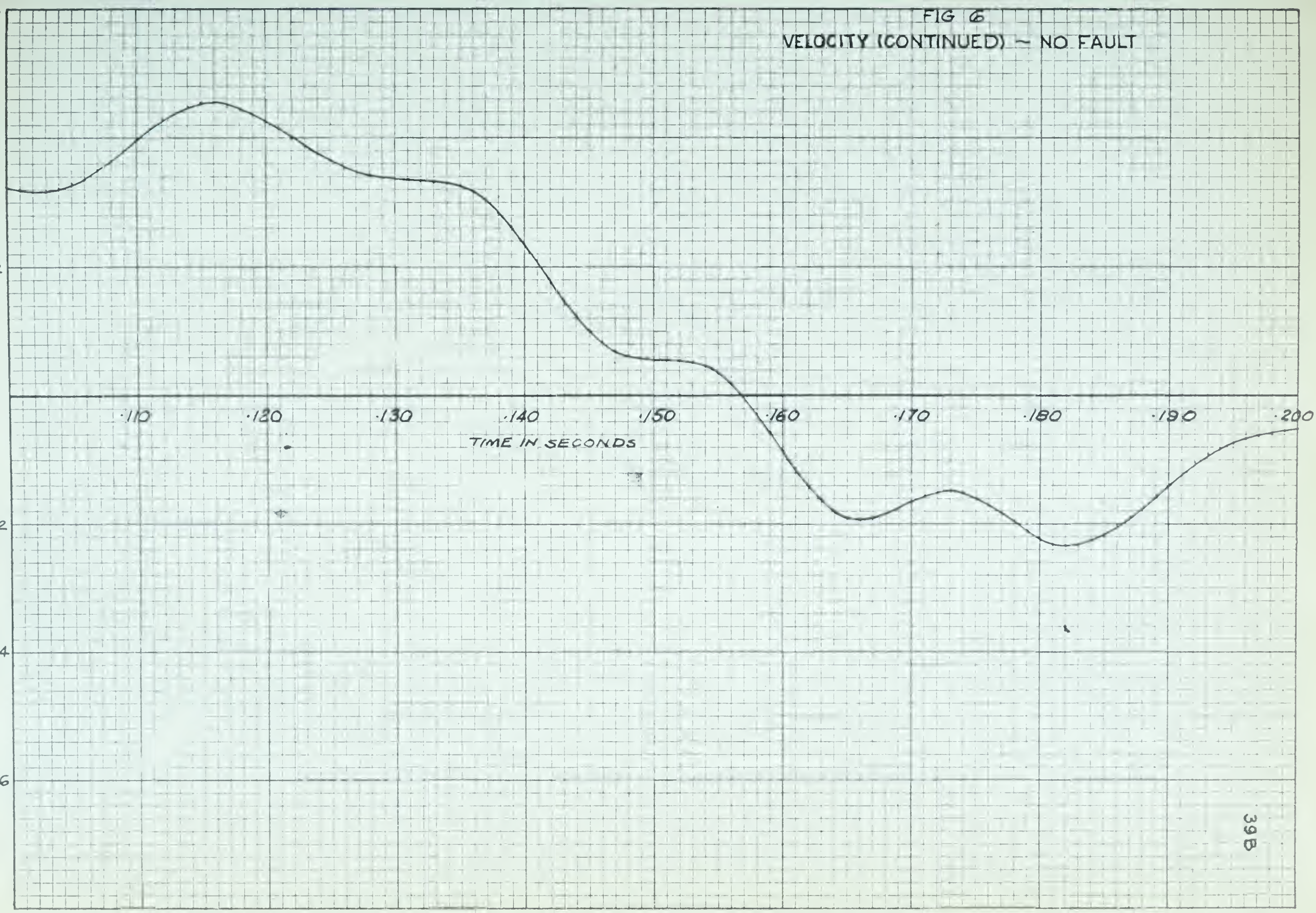
6
4
2
-2
-4
-6

.01 .02 .03 .04 .05 .06 .07 .08 .09 .10

39A

FIG 6

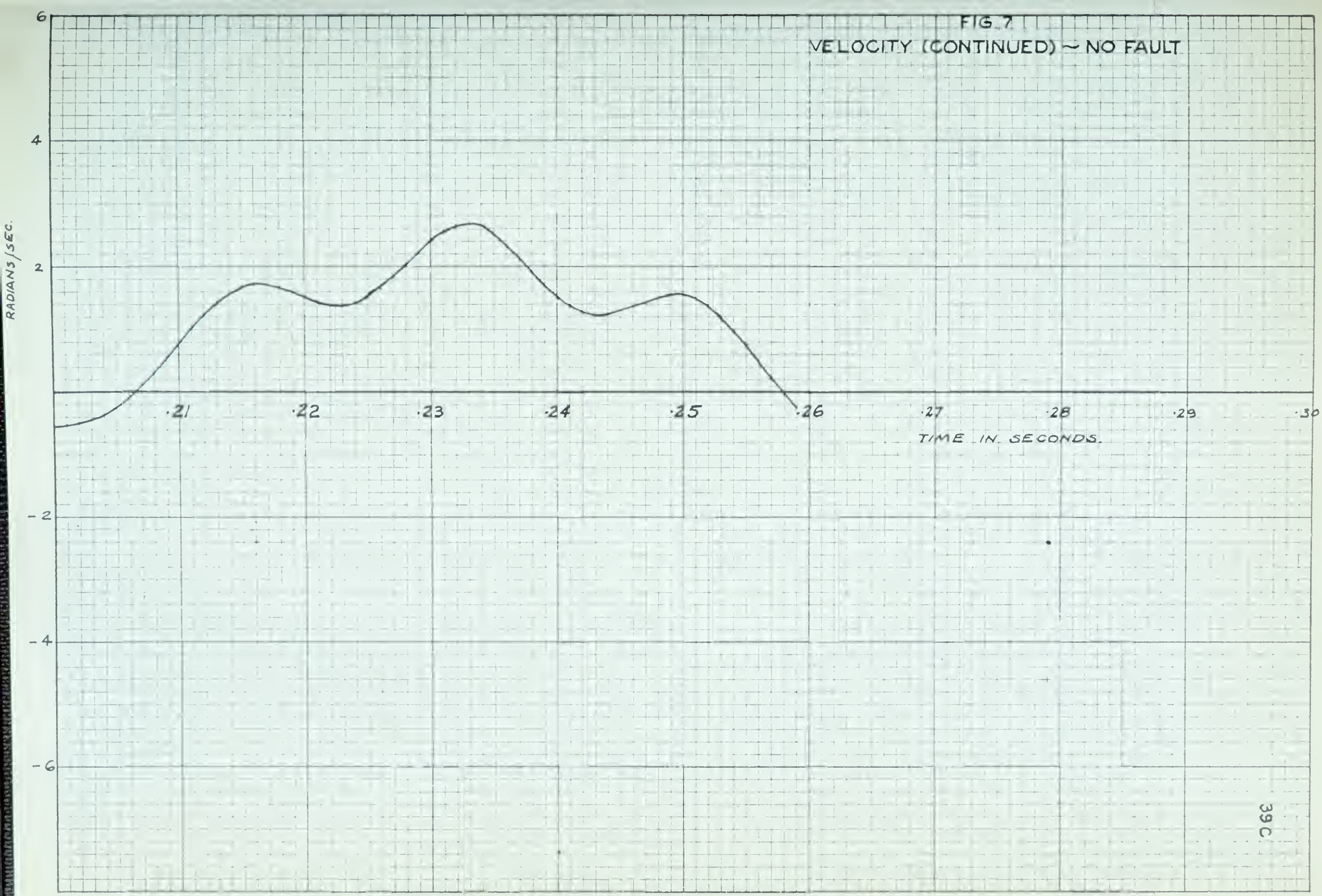
VELOCITY (CONTINUED) ~ NO FAULT



39B

FIG. 7

VELOCITY (CONTINUED) ~ NO FAULT



39C

FIG. 8 DISPLACEMENT — NO FAULT

$r_\alpha = 0.383\ \Omega$ $r_\beta = 0.062\ \Omega$

$L_\alpha = 0.0033371\ h$ $L_\beta = 0.0005199\ h$

$f_\alpha = 376.991119\ r/s$ $f_\beta = 350\ r/s$

$V_\alpha = 128\ v$ $V_\beta = 85.5\ v$

$\phi_0 = 0.0192\ r$ $m = 0.04955\ h$

$i_{\alpha 1_0} = 0.123 - j\,6.42\ a$ $J = 0.223$ $R = 0.149$

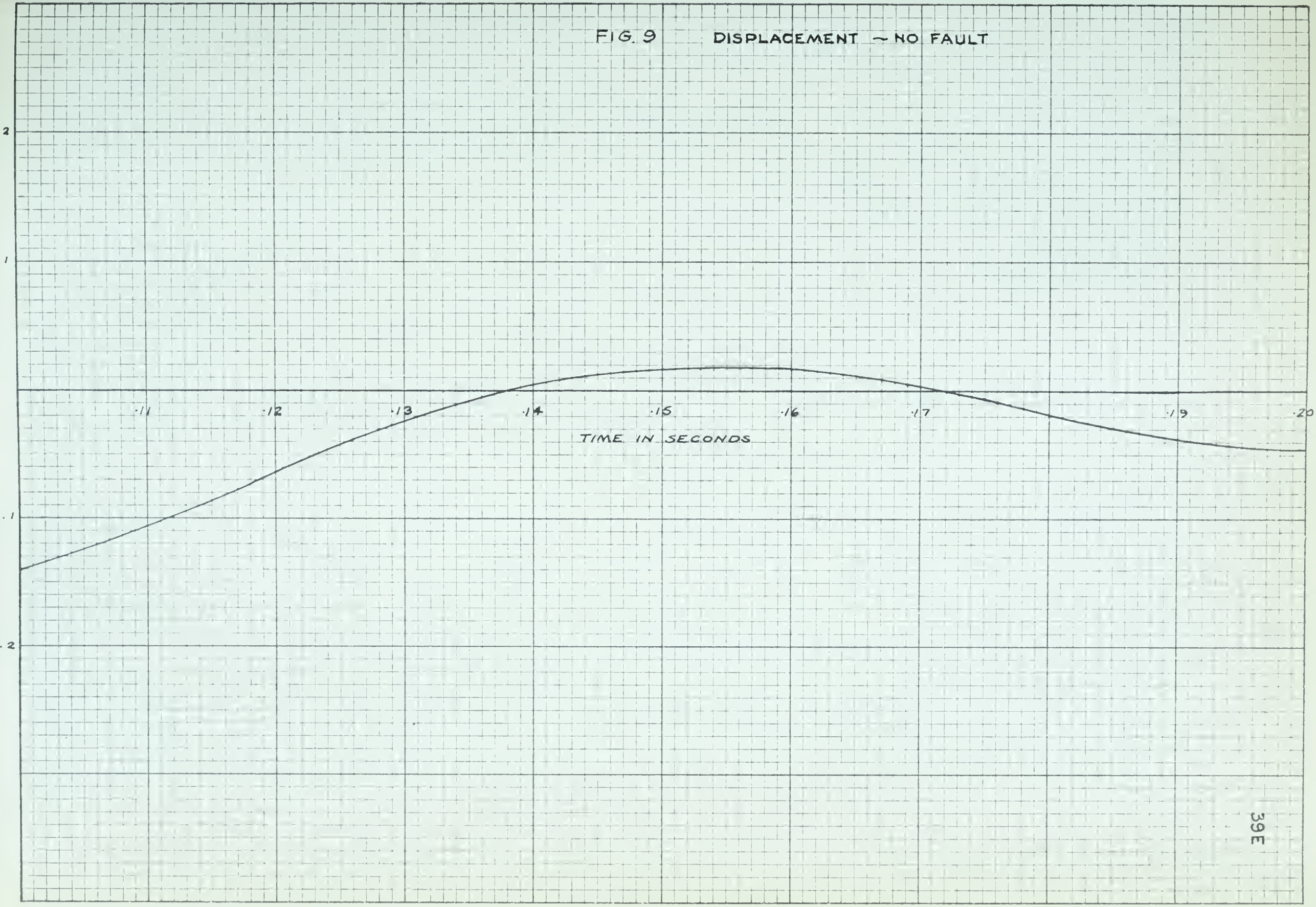
$i_{\alpha 2_0} = i_{\beta 1_0} = i_{\beta 2_0} = 0$

RADIANS

.2
.1
-.1
-.2

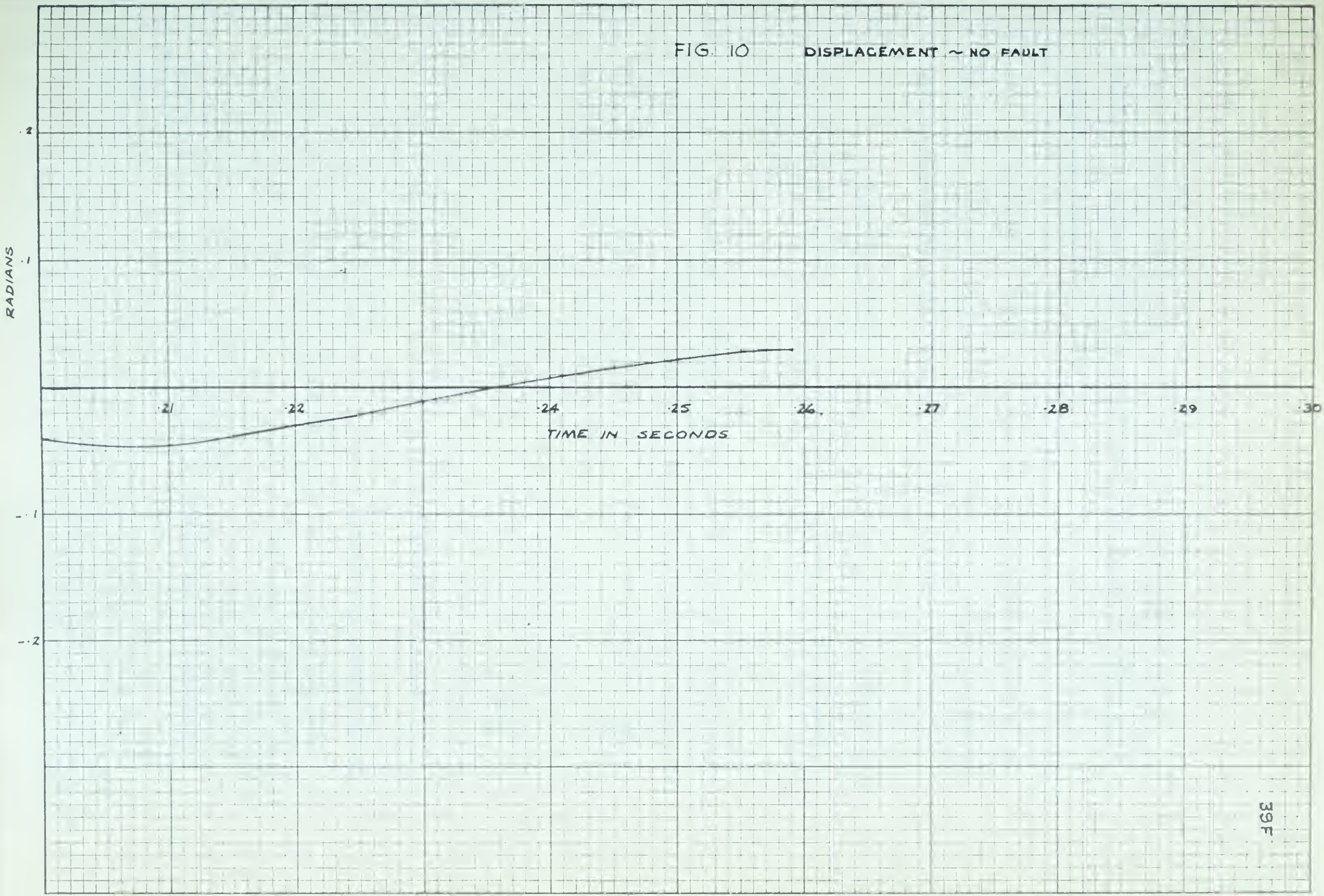
.01 .02 .03 .04 .05 .06 .07 .08 .09 .10

FIG. 9 DISPLACEMENT — NO FAULT



39E

FIG. 10 DISPLACEMENT ~ NO FAULT



times coincide in a rough manner with the periods of the stator voltages. The peak acceleration observed was about 370 electrical radians per second per second.

Figures 5, 6 and 7 display the rotor angular velocity in electrical radians per second. The velocity is a complex, periodic, and ill behaved function which is clearly unstable.

Figures 8, 9 and 10 display the rotor angular displacement in electrical radians. The displacement function clearly displays instability.

The digital computer was programmed in such a manner that a fault could be imposed at any time from start of double excitation until fifteen seconds after the start of double excitation. The following types of faults are considered:

(a) A three phase fault on either stator or rotor

(b) A line-to-ground fault on either stator or rotor

(c) A line-to-line fault on either stator or rotor

(d) A line-to-line fault on both stator and rotor.

The three phase fault is very uninteresting insofar as the doubly excited induction machine is concerned. A severe but brief power inrush occurs to cause the rotor to accelerate to normal speed. The faulted system is clearly in serious trouble but the unfaulted system and the doubly excited induction machine are not seriously affected.

The line-to-ground fault could pass zero sequence current through the machine but, with the neutral points ungrounded, zero sequence currents would be negligible.

The line-to-line fault on either stator or rotor applies negative sequence potentials to the side faulted, causing negative sequence currents to flow in the side faulted, inducing potentials of negative sequence in the unfaulted side and causing currents of negative sequence to flow in the unfaulted side. Clearly, however, the negative sequence current in the unfaulted side would have some impedance through which to flow and this voltage drop would be transformed to the faulted side. Thus the fault current in the doubly excited induction machine would be limited to some extent.

The line-to-line fault on either stator or rotor suggests an examination of the case where both stator and rotor have a line-to-line fault. The negative sequence currents would be most severe under these circumstances.

Clearly, if the doubly-excited wound rotor induction machine can withstand the worst of four cases it can withstand all cases. Clearly the wisest choice is to study the worst possible case as far as fault currents are concerned. For this reason the program was designed so that symmetrical double excitation or line-to-line faults on both rotor and stator could be selected at the discretion of the operator.

FIG 11

POSITIVE SEQUENCE ROTOR CURRENT

LINE TO LINE FAULT

$r_\alpha = 0.383\,\Omega$ $\quad r_\beta = 0.0620\,\Omega$

$L_\alpha = 0.003371\,h$ $\quad L_\beta = 0.000599\,h$

$f_\alpha = 376.991119\,r/s$ $\quad f_\beta = 350\,r/s$

$V_\alpha = 128\,V$ $\quad V_\beta = 85.5\,V$

$\phi_0 = 0.0192\,r$ $\quad m = 0.04955\,h$

$i_{\alpha 1_0} = 0.123 - j\,6.42a$

$i_{\alpha 2_0} = i_{\beta 1_0} = i_{\beta 2_0} = 0$

$J = 0.223$ $\quad R = 0.149$

$V_{\alpha 1} = V_{\alpha 2}$ $\quad V_{\beta 1} = V_{\beta 2}$

IMAGINARY AMPS.

REAL AMPS.

$T_1 = 0.0166$ sec.

$T_2 = 0.0333$ sec.

$T_3 = 0.0500$ sec.

$T_4 = 0.0666$ sec.

FIG 12

POSITIVE SEQUENCE STATOR CURRENT

LINE TO LINE FAULT

$r_\alpha = 0.383\ \Omega$ $\quad r_\beta = 0.062\ \Omega$

$L_\alpha = 0.003371\ h$ $\quad L_\beta = 0.0005199\ h$

$f_\alpha = 376.991119\ r/s$ $\quad f_\beta = 350\ r/s$

$V_\alpha = 128\ V$ $\quad V_\beta = 85.5\ V$

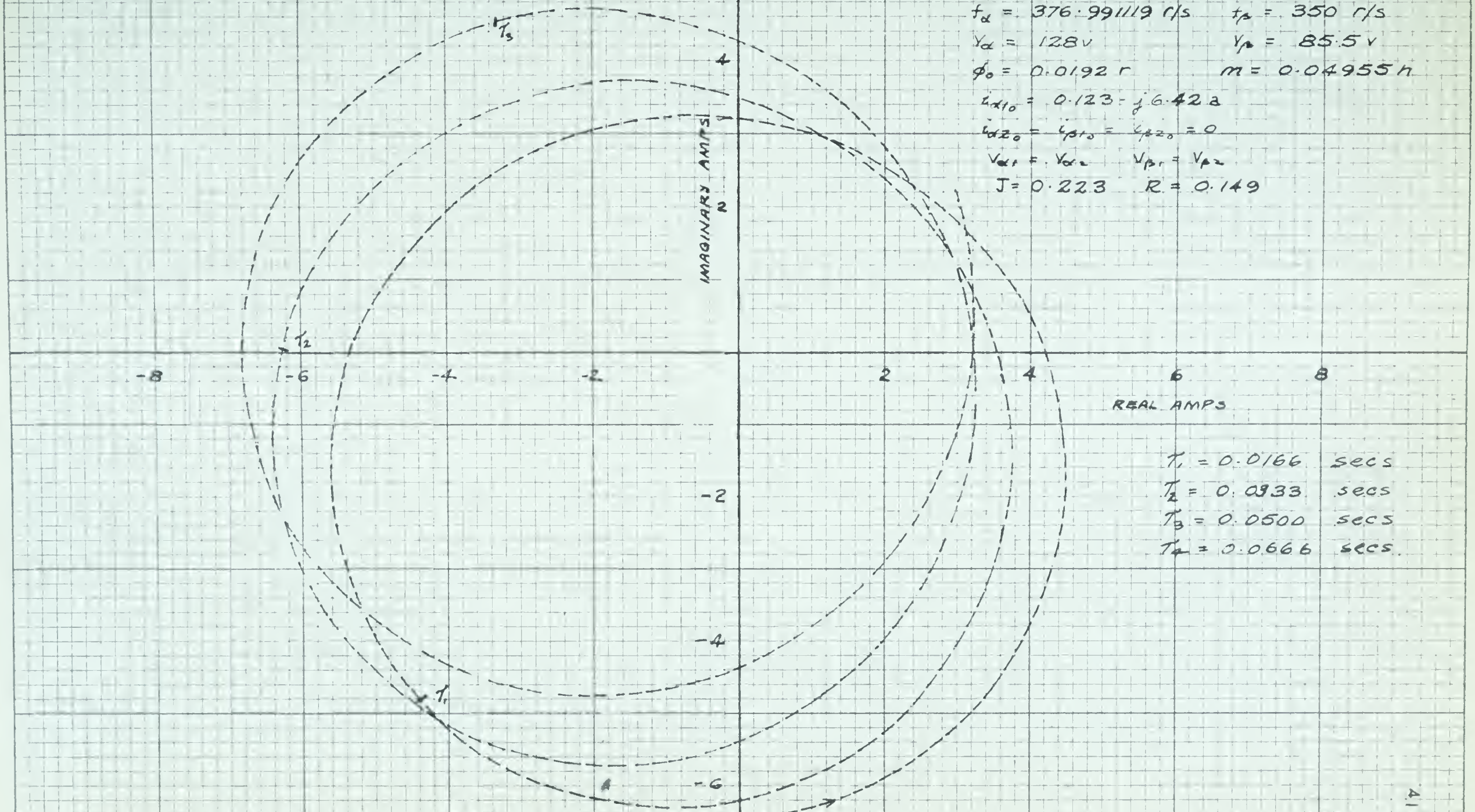
$\phi_0 = 0.0192\ r$ $\quad m = 0.04955\ h$

$z_{\alpha 1_0} = 0.123 - j\,6.42\ \Omega$

$i_{\alpha z_0} = i_{\beta 1_0} = i_{\beta z_0} = 0$

$V_{\alpha 1} = V_{\alpha 2}$ $\quad V_{\beta 1} = V_{\beta 2}$

$J = 0.223$ $\quad R = 0.149$



$T_1 = 0.0166$ secs

$T_2 = 0.0933$ secs

$T_3 = 0.0500$ secs

$T_4 = 0.0666$ secs

FIG. 13

NEGATIVE SEQUENCE STATOR CURRENT

LINE TO LINE FAULT

$r_\alpha = 0.383\ \Omega$ $\quad r_\beta = 0.062\ \Omega$

$L_\alpha = 0.003371\ h$ $\quad L_\beta = 0.0005199\ h$

$f_\alpha = 376.99111.9\ r/s$ $\quad f_\beta = 350\ r/s$

$V_\alpha = 128\ v$ $\quad V_\beta = 85.5\ v$

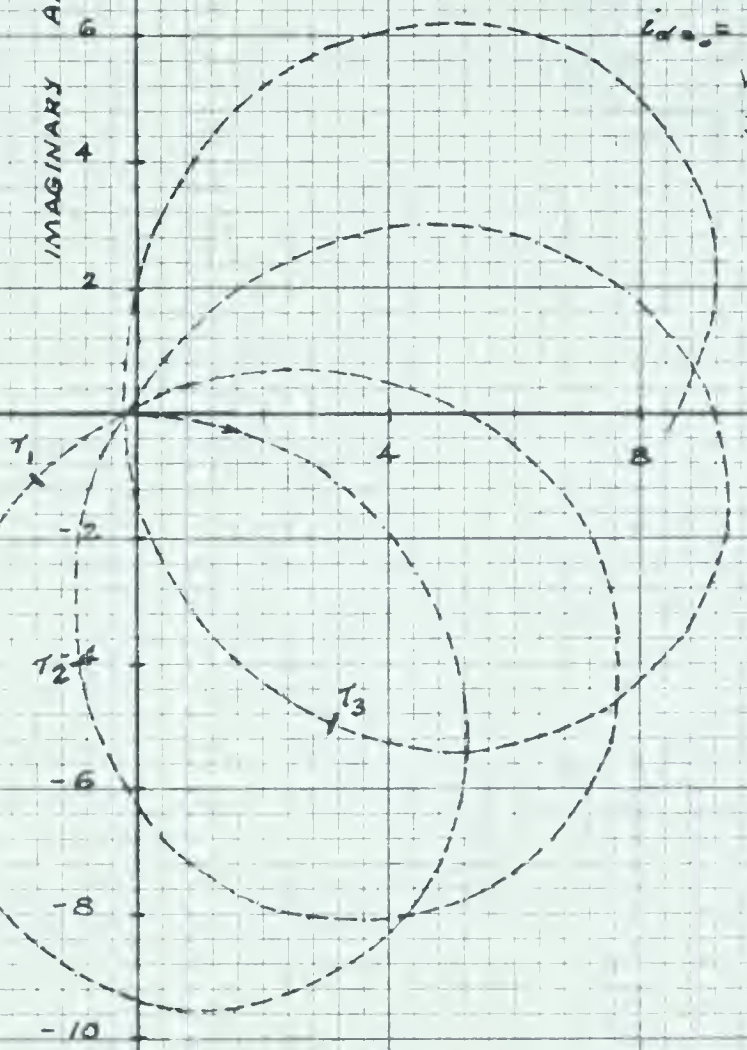
$\phi_0 = 0.0192\ r$ $\quad m = 0.04955\ h$

$i_{\alpha 1_0} = 0.123 - j\,6.42\ a$

$i_{\alpha 2_0} = i_{\beta 1_0} = i_{\beta 2_0} = 0$

$V_{\alpha 1} = V_{\alpha 2}$ $\quad V_{\beta 1} = V_{\beta 2}$

$J = 0.223$ $\quad R = 0.149$



$T_1 = 0.0166$ secs

$T_2 = 0.0333$ secs

$T_3 = 0.0500$ secs

4 | C

FIG. 14

NEGATIVE SEQUENCE ROTOR CURRENT

LINE TO LINE FAULT

$r_\alpha = 0.383\,\Omega$ $\quad r_\beta = 0.062\,\Omega$

$L_\alpha = 0.003371\,h$ $\quad L_\beta = 0.0005199\,h$

$f_\alpha = 376.991119$ r/s $\quad f_\beta = 350$ r/s

$V_\alpha = 128$ v $\quad V_\beta = 85.5$ v

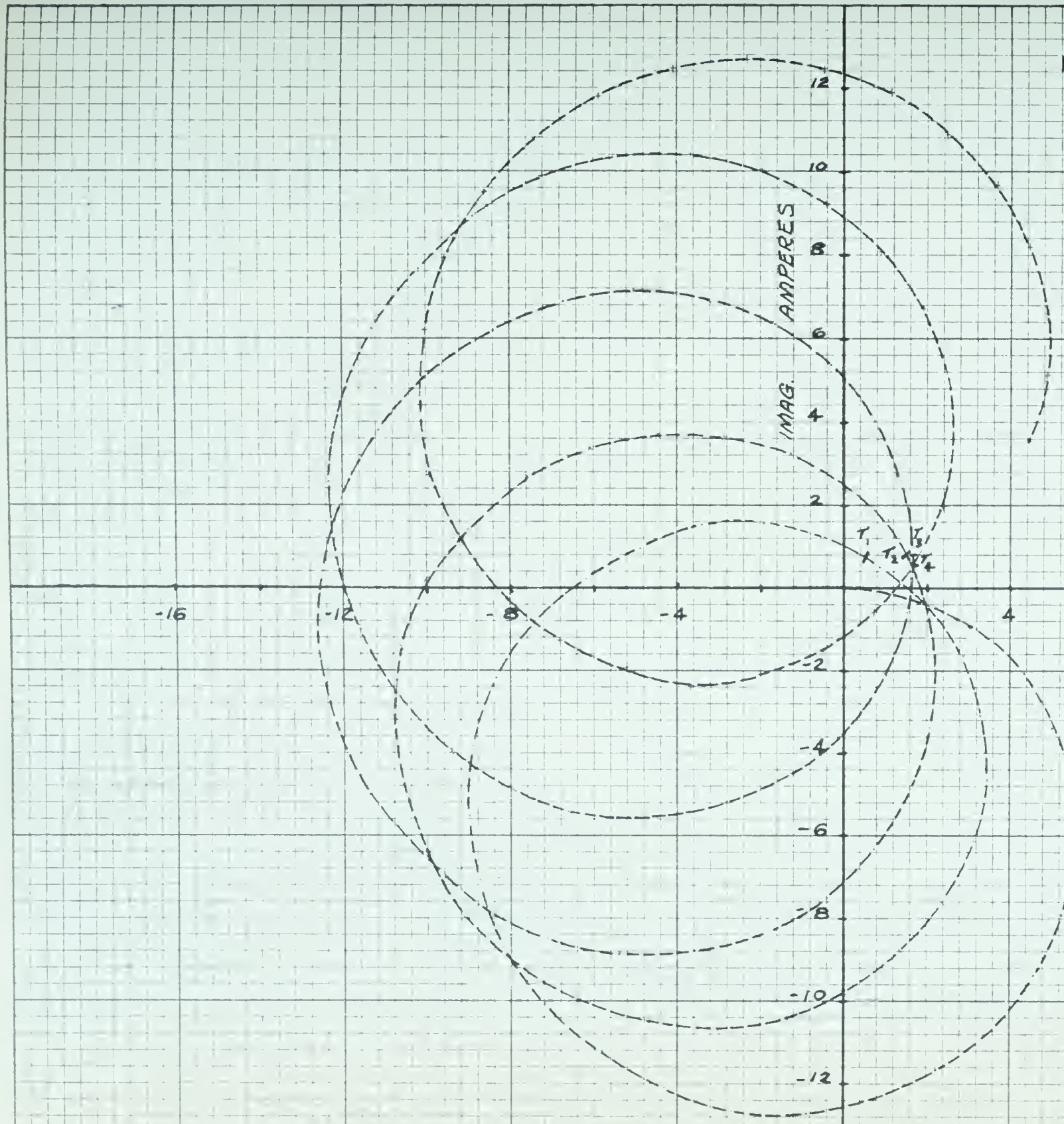
$\phi_0 = 0.0192\,r$ $\quad m = 0.04955\,h$

$i_{\alpha 1_0} = 0.123 - j\,6.42\,a$

$i_{\alpha 2_0} = i_{\beta 1_0} = i_{\beta 2_0} = 0$

$V_{\alpha 1} = V_{\alpha 2}$ $\quad V_{\beta 1} = V_{\beta 2}$

$J = 0.223$ $\quad R = 0.149$



$T_1 = 0.0166$ secs

$T_2 = 0.0333$ secs

$T_3 = 0.0500$ secs

$T_4 = 0.0606$ secs.

FIG 15

ACCELERATION

LINE TO LINE FAULT

$r_\alpha = 0.383\,\Omega$ $\quad r_\beta = 0.062\,\Omega$

$L_\alpha = 0.003371\,h$ $\quad L_\beta = 0.0005199\,h$

$f_\alpha = 376.991119\,r/s$ $\quad f_\beta = 350\,r/s$

$V_\alpha = 128\,V$ $\quad V_\beta = 85.5\,V$

$\phi_0 = 0.0192\,r$ $\quad m = 0.04955\,h$

$i_{\alpha 1_0} = 0.123 - j\,6.42\,a$

$i_{\alpha 2_0} = i_{\beta 1_0} = i_{\beta 2_0} = 0$

$V_{\alpha 1} = V_{\alpha 2}$ $\quad V_{\beta 1} = V_{\beta 2}$

$J = 0.223$ $\quad R = 0.149$

RADIANS / SEC²

500
400
300
200
100
0
-100
-200
-300
-400
-500
-600

·01 ·02 ·03 ·04 ·05 ·06 ·07 ·08 ·09 ·10

TIME IN SECONDS

41E

FIG. 16

VELOCITY OF ROTOR

LINE TO LINE FAULT

$r_\alpha = 0.383\,\Omega$ $\quad r_\beta = 0.062\,\Omega$

$L_\alpha = 0.0033711\,h$ $\quad L_\beta = 0.0005199\,h$

$f_\alpha = 376.991119$ r/s $\quad f_\beta = 350$ r/s

$V_\alpha = 128$ V $\quad V_\beta = 85.5$ V

$\phi_0 = 0.0192$ r $\quad m = 0.04955\,h$

$i_{\alpha 1_0} = 0.123 - j\,6.42$ a $\quad V_{\alpha 1} = V_{\alpha 2} \quad V_{\beta 1} = V_{\beta 2}$

$i_{\alpha 2_0} = i_{\beta 1_0} = i_{\beta 2_0} = 0$ $\quad J = 0.223 \quad R = 0.149$

RADIANS PER SECOND

10
8
6
4
2
-2
-4
-6
-8
-10
-12

.01 .02 .03 .04 .05 .06 .07 .08 .09 .10

TIME IN SECONDS

41F

Figure 11 displays typical counter-clockwise motion and is therefore the locus of a positive sequence function. It is the locus of the positive sequence rotor current under the fault condition selected above. Fig. 11 is quite similar in nature to Fig. 2.

Fig. 12 is also the locus of a positive sequence function. It is the locus of the positive sequence stator current under the fault conditions described above. Fig. 12 is very similar to Fig. 1.

Fig. 13 displays the negative sequence stator current under the fault conditions described. The peak negative sequence current is about 9.8 amperes. Irregularities are due to a slight error in the program which had a tendency to neglect the imaginary component of rotor negative sequence resistive potential drop. This error was discovered after all the loci had been plotted. Changes were made to the program but the program was not re-run.

Fig. 14 displays the negative sequence rotor current. The peak magnitude of negative sequence rotor current is about 13 amperes. Any irregularities are due to the error described under Fig. 13.

Fig. 15 displays the rotor acceleration in electrical radians per second per second. The peak acceleration is about - 520 electrical radians per second per second. The rotor acceleration is periodic and has nearly the same periods as in the unfaulted case. However the accelerations are quite different in the two cases.

Fig. 16 displays the rotor velocity in electrical radians

1.1
0
-.1
-.2
-.3
-.4
-.5
-.6
RADIANS

.01 .02 .03 .04 .05 .06 .07 .08 .09 .10

TIME IN SECONDS

FIG 17

DISPLACEMENT OF ROTOR

LINE TO LINE FAULT

$r_\alpha = 0.383\,\Omega$ $r_\beta = 0.062\,\Omega$

$L_\alpha = 0.003371\,h$ $f_\beta = 350\,r/s$

$f_\alpha = 376.991119\,r/s$ $L_\beta = 0.0005199\,h$

$V_\alpha = 128\,V$ $V_\beta = 85.5\,V$

$\phi_0 = 0.0192\,r$ $m = 0.04955\,h$

$i_{d1_0} = 0.123 - j\,6.42\,A$ $V_{\alpha 1} = V_{\alpha 2}$ $V_{\beta 1} = V_{\beta 2}$

$i_{d2_0} = i_{\beta 1_0} = i_{\beta 2_0} = 0$ $J = 0.223$ $R = 0.149$

42A

per second under the fault conditions. The velocity is in the wrong direction and therefore indicates instability.

Fig. 17 displays the rotor displacement in electrical radians under the fault conditions. The displacement is in the wrong direction and indicates instability.

Figures 1 through 17 were the results of calculations performed by a digital computer.

A test of the doubly-excited induction "motor" was made. With a small shaft load the writer found that two synchronous systems could be asynchronously connected provided that they were "asynchronously" connected at the same frequency before any changes in frequency occurred. Even so, large fluctuations in currents and powers nullified the test except to indicate as follows:

(a) Power can be asynchronously interchanged

(b) The magnitude of power flow can be changed by changing the ratios of stator to rotor potentials.

When the small shaft load was uncoupled the doubly excited induction machine became unstable and the experiment was stopped.

II. CONCLUSIONS

For the machine studied in the laboratory, the digital computer study indicates instability if the difference in applied frequency exceeds 26.991118 radians per second. This is equivalent to some 4.3 cycles per second. Probably instability would occur at lower speeds and frequency differences although such tests and calculations were not made.

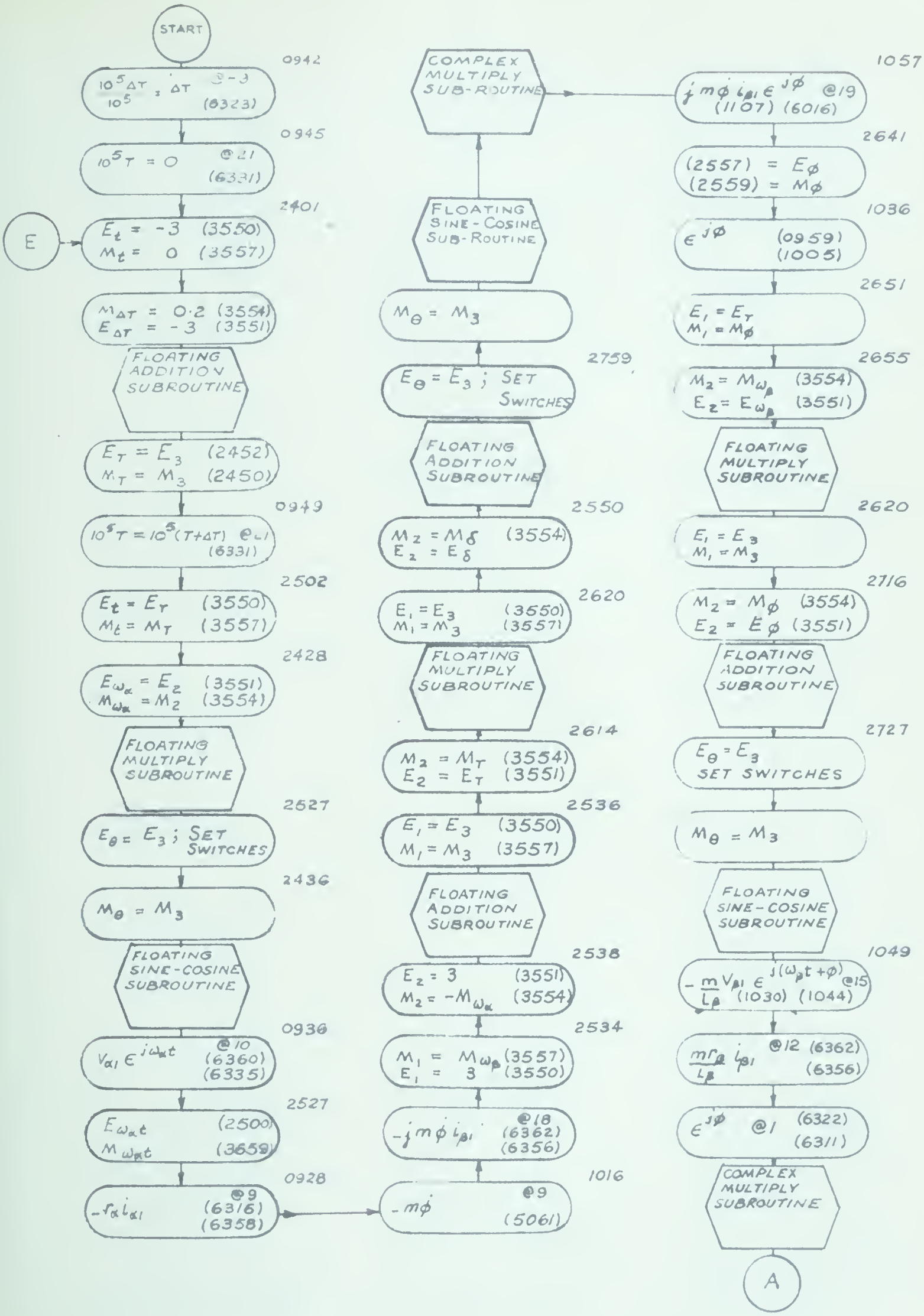
This instability is attributed to lack of rotor damping circuits. A digital computer study of such machinery with rotor damping circuits would require a digital computer of much greater capacity than the Royal McBee LGP 30.

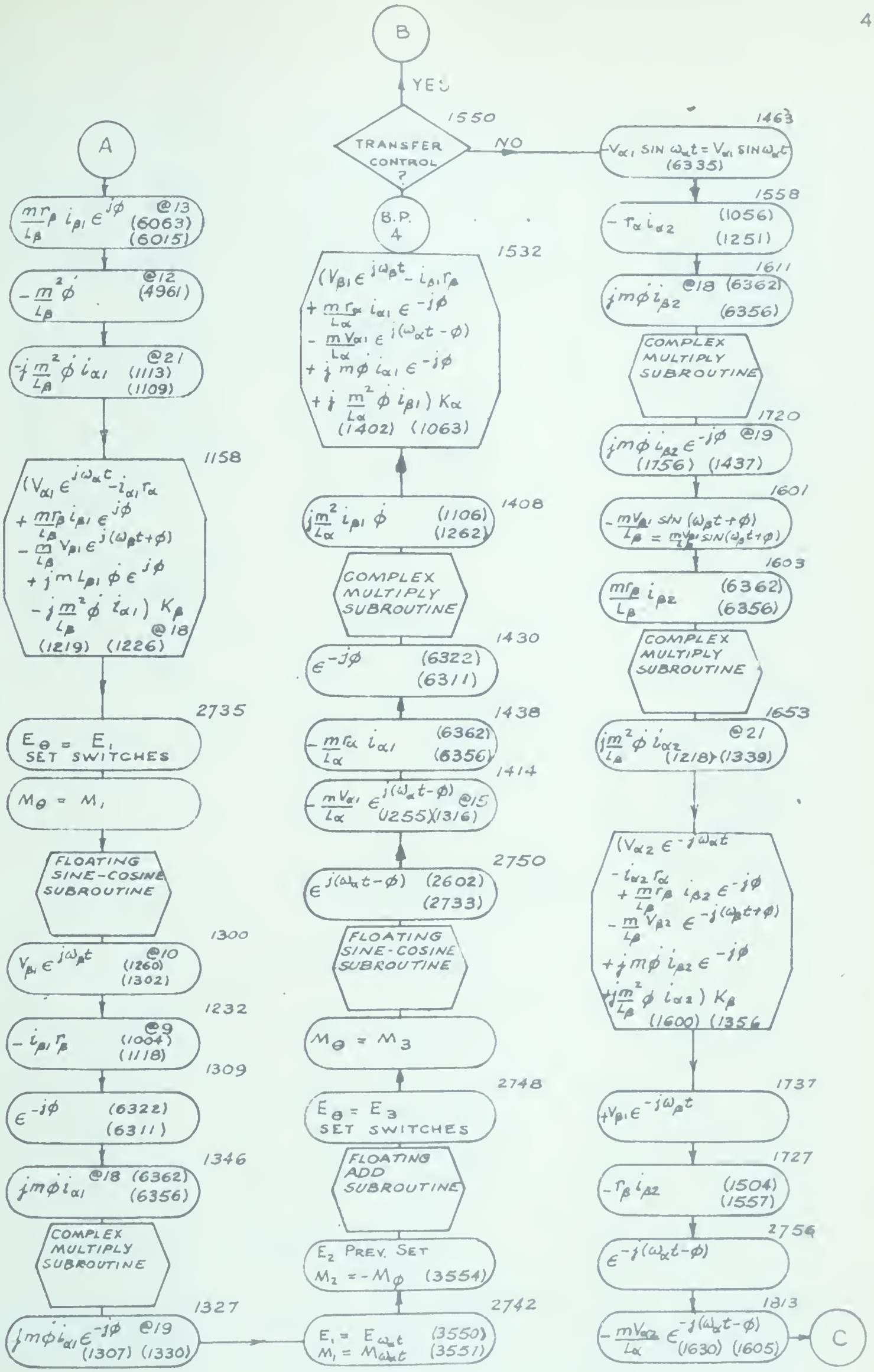
APPENDIX A

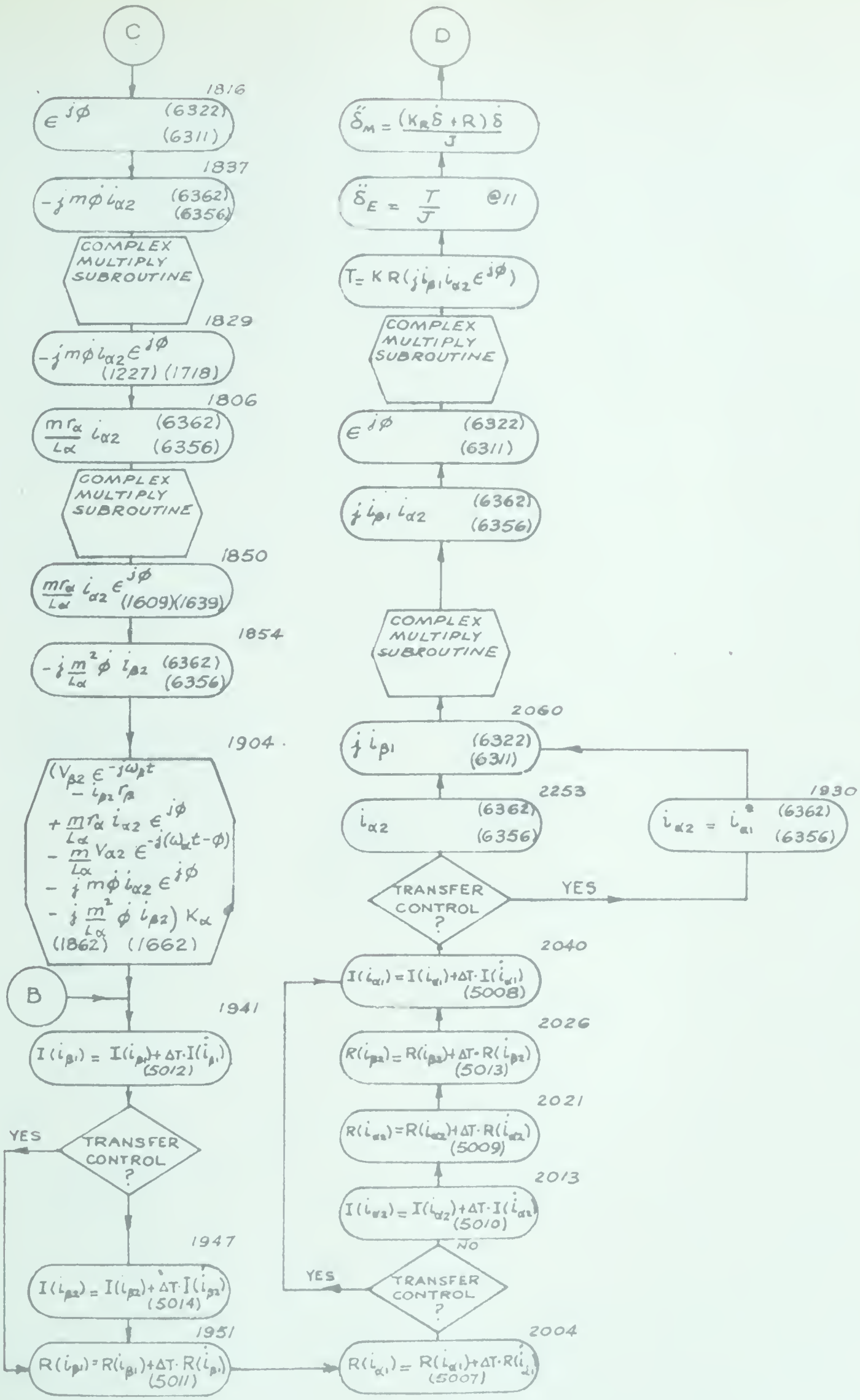
CODING SHEETS FOR ELECTRONIC DIGITAL COMPUTER

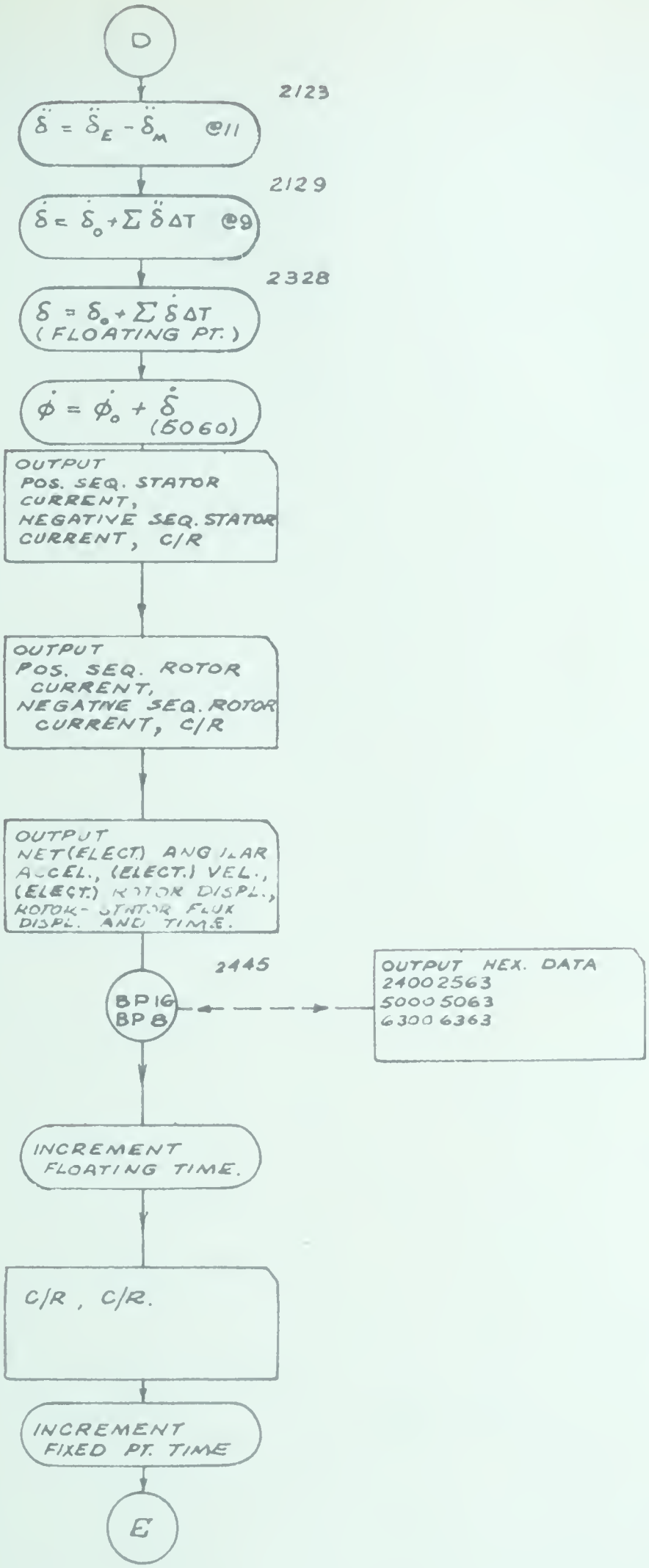
A PROGRAM FOR THE

ROYAL McBEE LGP 30


START
0942
$10^5\Delta T = \Delta T$ @-3
10^5 (6323)
0945
$10^5 T = 0$ @21
(6331)
2401
E
$E_t = -3$ (3550)
$M_t = 0$ (3557)
$M_{\Delta T} = 0.2$ (3554)
$E_{\Delta T} = -3$ (3551)
FLOATING ADDITION SUBROUTINE
$E_T = E_3$ (2452)
$M_T = M_3$ (2450)
0949
$10^5 T = 10^5(T+\Delta T)$ @21
(6331)
2502
$E_t = E_T$ (3550)
$M_t = M_T$ (3557)
2428
$E_{\omega_\alpha} = E_2$ (3551)
$M_{\omega_\alpha} = M_2$ (3554)
FLOATING MULTIPLY SUBROUTINE
2527
$E_\theta = E_3$; SET SWITCHES
2436
$M_\theta = M_3$
FLOATING SINE-COSINE SUBROUTINE
0936
$V_{\alpha 1} \epsilon^{i\omega_\alpha t}$ @10
(6360) (6335)
2527
$E_{\omega_\alpha t}$ (2500)
$M_{\omega_\alpha t}$ (3659)
0928
$-r_\alpha i_{\alpha 1}$ @9
(6316) (6358)
COMPLEX MULTIPLY SUB-ROUTINE
FLOATING SINE-COSINE SUB-ROUTINE
$M_\theta = M_3$
2759
$E_\theta = E_3$; SET SWITCHES
FLOATING ADDITION SUBROUTINE
2550
$M_2 = M_\delta$ (3554)
$E_2 = E_\delta$
2620
$E_1 = E_3$ (3550)
$M_1 = M_3$ (3557)
FLOATING MULTIPLY SUBROUTINE
2614
$M_2 = M_T$ (3554)
$E_2 = E_T$ (3551)
2536
$E_1 = E_3$ (3550)
$M_1 = M_3$ (3557)
FLOATING ADDITION SUBROUTINE
2538
$E_2 = 3$ (3551)
$M_2 = -M_{\omega_\alpha}$ (3554)
2534
$M_1 = M_{\omega_\beta}$ (3557)
$E_1 = 3$ (3550)
$-jm\phi i_{\beta 1}$ @18
(6362) (6356)
1016
$-m\phi$ @9
(5061)
1057
$jm\phi i_{\beta 1} \epsilon^{j\phi}$ @19
(1107) (6016)
2641
(2557) = E_ϕ
(2559) = M_ϕ
1036
$\epsilon^{j\phi}$ (0959) (1005)
2651
$E_1 = E_T$
$M_1 = M_\phi$
2655
$M_2 = M_{\omega_\beta}$ (3554)
$E_2 = E_{\omega_\beta}$ (3551)
FLOATING MULTIPLY SUBROUTINE
2620
$E_1 = E_3$
$M_1 = M_3$
2716
$M_2 = M_\phi$ (3554)
$E_2 = E_\phi$ (3551)
FLOATING ADDITION SUBROUTINE
2727
$E_\theta = E_3$
SET SWITCHES
$M_\theta = M_3$
FLOATING SINE-COSINE SUBROUTINE
1049
$-\frac{m}{L_\beta} V_{\beta 1} \epsilon^{j(\omega_\beta t + \phi)}$ @15
(1030) (1044)
$\frac{mr_\beta}{L_\beta} i_{\beta 1}$ @12 (6362)
(6356)
$\epsilon^{j\phi}$ @1 (6322)
(6311)
COMPLEX MULTIPLY SUBROUTINE
A


A
$\frac{mr_\beta}{L_\beta} i_{\beta 1} \epsilon^{j\phi}$ @13 (6063) (6015)
$-\frac{m^2}{L_\beta}\phi$ @12 (4961)
$-j\frac{m^2}{L_\beta}\phi\, i_{\alpha 1}$ @21 (1113) (1109)
1158
$(V_{\alpha 1}\epsilon^{j\omega_\alpha t} - i_{\alpha 1} r_\alpha + \frac{mr_\beta}{L_\beta} i_{\beta 1}\epsilon^{j\phi} - \frac{m}{L_\beta} V_{\beta 1}\epsilon^{j(\omega_\beta t+\phi)} + jm L_{\beta 1}\phi\,\epsilon^{j\phi} - j\frac{m^2}{L_\beta}\phi\, i_{\alpha 1})\, K_\beta$ @18 (1219) (1226)
2735
$E_\theta = E_1$ SET SWITCHES
$M_\theta = M_1$
FLOATING SINE-COSINE SUBROUTINE
1300
$V_{\beta 1}\epsilon^{j\omega_\beta t}$ @10 (1260) (1302)
1232
$-i_{\beta 1} r_\beta$ @9 (1004) (1118)
1309
$\epsilon^{-j\phi}$ (6322) (6311)
1346
$jm\phi\, i_{\alpha 1}$ @18 (6362) (6356)
COMPLEX MULTIPLY SUBROUTINE
1327
$jm\phi\, i_{\alpha 1}\epsilon^{-j\phi}$ @19 (1307) (1330)
B
YES
1550
TRANSFER CONTROL ?
NO
B.P. 4
1532
$(V_{\beta 1}\epsilon^{j\omega_\beta t} - i_{\beta 1} r_\beta + \frac{mr_\alpha}{L_\alpha} i_{\alpha 1}\epsilon^{-j\phi} - \frac{mV_{\alpha 1}}{L_\alpha}\epsilon^{j(\omega_\alpha t-\phi)} + jm\phi\, i_{\alpha 1}\epsilon^{-j\phi} + j\frac{m^2}{L_\alpha}\phi\, i_{\beta 1})\, K_\alpha$ (1402) (1063)
1408
$j\frac{m^2}{L_\alpha} i_{\beta 1}\phi$ (1106) (1262)
COMPLEX MULTIPLY SUBROUTINE
1430
$\epsilon^{-j\phi}$ (6322) (6311)
1438
$-\frac{mr_\alpha}{L_\alpha} i_{\alpha 1}$ (6362) (6356)
1414
$-\frac{mV_{\alpha 1}}{L_\alpha}\epsilon^{j(\omega_\alpha t-\phi)}$ @15 (0255)(1316)
2750
$\epsilon^{j(\omega_\alpha t-\phi)}$ (2602) (2733)
FLOATING SINE-COSINE SUBROUTINE
$M_\theta = M_3$
2748
$E_\theta = E_3$ SET SWITCHES
FLOATING ADD SUBROUTINE
E_2 PREV. SET $M_2 = -M_\phi$ (3554)
2742
$E_1 = E_{\omega_\alpha t}$ (3550) $M_1 = M_{\omega_\alpha t}$ (3551)
1463
$-V_{\alpha 1}\sin\omega_\alpha t = V_{\alpha 1}\sin\omega_\alpha t$ (6335)
1558
$-r_\alpha i_{\alpha 2}$ (1056) (1251)
1611
$jm\phi\, i_{\beta 2}$ @18 (6362) (6356)
COMPLEX MULTIPLY SUBROUTINE
1720
$jm\phi\, i_{\beta 2}\epsilon^{-j\phi}$ @19 (1756) (1437)
1601
$-\frac{mV_{\beta 1}\sin(\omega_\beta t+\phi)}{L_\beta} = \frac{mV_{\beta 1}\sin(\omega_\beta t+\phi)}{L_\beta}$
1603
$\frac{mr_\beta}{L_\beta} i_{\beta 2}$ (6362) (6356)
COMPLEX MULTIPLY SUBROUTINE
1653
$j\frac{m^2}{L_\beta}\phi\, i_{\alpha 2}$ @21 (1218) (1339)
$(V_{\alpha 2}\epsilon^{-j\omega_\alpha t} - i_{\alpha 2} r_\alpha + \frac{mr_\beta}{L_\beta} i_{\beta 2}\epsilon^{-j\phi} - \frac{m}{L_\beta} V_{\beta 2}\epsilon^{-j(\omega_\beta t+\phi)} + jm\phi\, i_{\beta 2}\epsilon^{-j\phi} + j\frac{m^2}{L_\beta}\phi\, i_{\alpha 2})\, K_\beta$ (1600) (1356)
1737
$+V_{\beta 1}\epsilon^{-j\omega_\beta t}$
1727
$-r_\beta i_{\beta 2}$ (1504) (1557)
2756
$\epsilon^{-j(\omega_\alpha t-\phi)}$
1813
$-\frac{mV_{\alpha 2}}{L_\alpha}\epsilon^{-j(\omega_\alpha t-\phi)}$ (1630) (1605)
C


C
1816
$\epsilon^{j\phi}$ (6322) (6311)
1837
$-j m\phi i_{\alpha 2}$ (6362) (6356)
COMPLEX MULTIPLY SUBROUTINE
1829
$-j m\phi i_{\alpha 2}\epsilon^{j\phi}$ (1227) (1718)
1806
$\frac{m r_\alpha}{L_\alpha} i_{\alpha 2}$ (6362) (6356)
COMPLEX MULTIPLY SUBROUTINE
1850
$\frac{m r_\alpha}{L_\alpha} i_{\alpha 2}\epsilon^{j\phi}$ (1609)(1639)
1854
$-j\frac{m^2}{L_\alpha}\phi\, i_{\beta 2}$ (6362) (6356)
1904
$(V_{\beta 2}\epsilon^{-j\omega_\beta t} - i_{\beta 2} r_\beta + \frac{m r_\alpha}{L_\alpha} i_{\alpha 2}\epsilon^{j\phi} - \frac{m}{L_\alpha} V_{\alpha 2}\epsilon^{-j(\omega_\alpha t-\phi)} - j m\phi i_{\alpha 2}\epsilon^{j\phi} - j\frac{m^2}{L_\alpha}\phi\, i_{\beta 2}) K_\alpha$
(1862) (1662)
B
1941
$I(i_{\beta 1}) = I(i_{\beta 1}) + \Delta T \cdot I(\dot{i}_{\beta 1})$ (5012)
YES
TRANSFER CONTROL ?
1947
$I(i_{\beta 2}) = I(i_{\beta 2}) + \Delta T \cdot I(\dot{i}_{\beta 2})$ (5014)
1951
$R(i_{\beta 1}) = R(i_{\beta 1}) + \Delta T \cdot R(\dot{i}_{\beta 1})$ (5011)
D
$\ddot{\delta}_M = \frac{(K_R\dot{\delta} + R)\dot{\delta}}{J}$
$\ddot{\delta}_E = \frac{T}{J}$ @11
$T = K R(j i_{\beta 1} i_{\alpha 2}\epsilon^{j\phi})$
COMPLEX MULTIPLY SUBROUTINE
$\epsilon^{j\phi}$ (6322) (6311)
$j i_{\beta 1} i_{\alpha 2}$ (6362) (6356)
COMPLEX MULTIPLY SUBROUTINE
2060
$j i_{\beta 1}$ (6322) (6311)
2253
$i_{\alpha 2}$ (6362) (6356)
1930
$i_{\alpha 2} = i^*_{\alpha 1}$ (6362) (6356)
TRANSFER CONTROL ?
YES
2040
$I(i_{\alpha 1}) = I(i_{\alpha 1}) + \Delta T \cdot I(\dot{i}_{\alpha 1})$ (5008)
2026
$R(i_{\beta 2}) = R(i_{\beta 2}) + \Delta T \cdot R(\dot{i}_{\beta 2})$ (5013)
2021
$R(i_{\alpha 2}) = R(i_{\alpha 2}) + \Delta T \cdot R(\dot{i}_{\alpha 2})$ (5009)
2013
$I(i_{\alpha 2}) = I(i_{\alpha 2}) + \Delta T \cdot I(\dot{i}_{\alpha 2})$ (5010)
NO
YES
TRANSFER CONTROL ?
2004
$R(i_{\alpha 1}) = R(i_{\alpha 1}) + \Delta T \cdot R(\dot{i}_{\alpha 1})$ (5007)


D
2123
$\ddot{\delta} = \ddot{\delta}_E - \ddot{\delta}_M$ @11
2129
$\dot{\delta} = \dot{\delta}_o + \Sigma \ddot{\delta} \Delta T$ @9
2328
$\delta = \delta_o + \Sigma \dot{\delta} \Delta T$
(FLOATING PT.)
$\phi = \phi_o + \dot{\delta}$
(5060)
OUTPUT
POS. SEQ. STATOR CURRENT,
NEGATIVE SEQ. STATOR CURRENT, C/R
OUTPUT
POS. SEQ. ROTOR CURRENT,
NEGATIVE SEQ. ROTOR CURRENT, C/R
OUTPUT
NET(ELECT.) ANGULAR ACCEL., (ELECT.) VEL., (ELECT.) ROTOR DISPL., ROTOR-STATOR FLUX DISPL. AND TIME.
2445
BP 16
BP 8
OUTPUT HEX. DATA
24002563
50005063
63006363
INCREMENT FLOATING TIME.
C/R , C/R.
INCREMENT FIXED PT. TIME
E

LGP-30 CODING SHEET
NO 1

PAGE 1 OF 4.0

PROG NO PREP BY K.A. DANE CK'D BY K.A. DANE DATE

EM TRANSIENT ANALYSIS OF DOUBLY EXCITED INDUCTION MOTOR TRACK 09 THROUGH 3363

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP	INSTRUCTION ADDRESS	TOF	CONTENTS OF ADDRESS	NOTES
	'						
	'	☒					
	'	09 00					
	'	01					
	'	02					
	'	03				☒	
	'	04					
	'	05					
	'	06					
	'	07				☒	
	'	08					
	'	09					
	'	10					
	'	11				☒	
	'	12					
	'	13					
	'	14					
	'	15				☒	
	'	16					
	'	17					
	'	18					
	'	19				☒	
	'	20					
	'	21					
	'	22					
	'	23				☒	
	'	24					
+016001 7	'	25	100000	' 000'		10^5 @17	
	'	26	[	]		t @4	
	'	27				☒	
	'	28	x S 5007			real part $\iota_{\alpha i}$ @9	
	'	29	x M 5000			r_α @0	
	'	30	x C 6316			real part - $\iota_{\alpha i} r_\alpha$ @9	
	'	31	x S 5008			☒ imaginary part $\iota_{\alpha i} r_\alpha$ @9	

CONDITIONAL STOP CODE ☒ CARRIAGE RETURN

PROG NO PREP BY CK'D BY DATE

M TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP	ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		09 32	x U 1 0 1 4				
		33					
		34					
		35					
		36	x B 6 3 2 2			$\cos \omega_\alpha t$ @1	
		37	x M 5 0 2 0			$V_{\alpha 1}$ @9	
		38	x C 6 3 6 0			Real Part $V_{\alpha 1} e^{i\omega_\alpha t}$ @10	
		39	x B 6 3 1 1			$\sin \omega_\alpha t$ @1	
		40	x M 5 0 2 0			$V_{\alpha 1}$ @9	
		41	x U 0 9 5 6				
		42	x B 6 3 2 8			$10^5 \Delta t$ @21	
		43	x D 6 3 2 9			10^5 @30	
		44	x C 6 3 2 3			Δt @-9	
		45	x C 6 3 3 1			$10^5 t = 0$ @21	
		46	x U 2 4 4 0				
		47	x M 5 0 1 1			Real Part $i_{\beta 1}$ @9	
		48	x U 1 0 0 6				
		49	x A 6 3 2 8			$10^5 \Delta t$ @21	
		50	x U 0 9 5 2				
		51	[	]			$\frac{m^2}{L\alpha}$ @3
		52	x H 6 3 3 1			$10^5 t$ @21	
		53	x D 0 9 2 5			10^5 @17	
		54	x H 0 9 2 6			t @4	
		55	x U 2 5 0 5				
		56	x C 6 3 3 5				
		57	x U 2 5 2 7				
		58					
		59	[	]			$\cos \phi$ @1 saved.
		60					
		61					
		62					
		63					

CONDITIONAL STOP CODE

CARRIAGE RETURN

LGP-30 CODING SHEET
NO 1

PROG NO PREP BY CK D BY DATE

M TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP	ADDRES	STOP	CONTENTS OF ADDRESS	NOTES
		1 0 0 0					
		0 1					
		0 2					
		0 3		1 0			
		0 4	[	]		$-i_{\beta 1} r_\beta$ @ 9 (real)	
		0 5	[	]			$\sin\phi$ @1 SAVED.
		0 6		x C 6 3 5 6		IMAGINARY PART $-j m\phi i_{\beta 1}$ @18	
		0 7		x U 1 0 2 5			
		0 8					
		0 9					
		1 0					
		1 1					
		1 2					
		1 3					
		1 4		x M 5 0 0 0		r_α @0	
		1 5		x C 6 3 5 8		imaginary part $-i_{\alpha 1} r_\alpha$ @9	
		1 6		x S 5 0 0 2		$-m$ @0	
		1 7		x M 5 0 6 0		$\dot{\phi}$ @9	
		1 8		x H 5 0 6 1		$-m\dot{\phi}$ @9	
		1 9		x U 0 9 4 7			
		2 0					
		2 1					
		2 2		x R 6 0 3 0		COMPUTE $-j m\phi i_{\beta 1} e^{j\phi}$ @19	
		2 3		x U 6 0 3 5			
		2 4		x U 1 0 5 7			
		2 5		x S 5 0 6 1		$+m\dot{\phi}$ @9	
		2 6		x M 5 0 1 2		imaginary part $i_{\beta 1}$ @9	
		2 7		x C 6 3 6 2		REAL PART $-j m\phi i_{\beta 1}$ @18	
		2 8		x U 2 5 3 4			
		2 9	[	]		$-\frac{m}{L_\alpha} V_{\alpha 1}$ @14	
		3 0	[	]		Real part $\{-\frac{m}{L_\beta} V_{\beta 1} \cos(\omega_\beta t + \phi)\}$ @15	
		3 1	[	]		$\frac{m r_\beta}{L_\beta}$ @3	

CONDITIONAL STOP CODE CARRIAGE RETURN

PROG NO. PREP BY CK D BY DATE

M TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP.	ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
	-						
	-	☒					
		1 0 3 2		1 0			
		3 3					
		3 4					
		3 5				☒	
		3 6	× B	6 3 2 2			SAVE $\cos\phi$
		3 7	× C	0 9 5 9			
		3 8	× U	1 0 5 3			
		3 9	[	]		☒	$\frac{mr_\beta}{L_\beta}$ @3
		4 0					
		4 1					
		4 2					
		4 3				☒	
		4 4	[	]		Imaginary Part	$\{-\frac{mV_{\beta 1}}{L_\beta} e^{j(\omega_\beta t+\phi)}\}$ @15
		4 5					
		4 6					
		4 7				☒	
		4 8					
		4 9	× B	1 1 0 0			$-(\frac{mV_{\beta 1}}{L_\beta})$ @14
		5 0	× M	6 3 2 2		$\cos(\omega_\beta t+\phi)$ @1	
		5 1	× C	1 0 3 0		☒	
		5 2	× U	1 0 6 0			
		5 3	× B	6 3 1 1			
		5 4	× C	1 0 0 5			
		5 5	× U	2 6 5 1		☒	
		5 6	[	]		$-b_{\alpha z} r_\alpha$ @9 (real part)	
		5 7	× B	6 0 1 5			
		5 8	× C	6 0 1 6			
		5 9	× U	1 1 2 0		☒	
		6 0	× B	6 3 1 1		$\sin(\omega_\beta t+\phi)$ @1	
		6 1	× U	1 1 1 4			
		6 2	[	]		temp. stor.	
		6 3	[	]		☒ imag. part ($i_{\beta 1}$) @18	

CONDITIONAL STOP CODE ☒ CARRIAGE RETURN

PROG NO PREP BY CK'D BY DATE

M TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP	ADDRESS	TOP	CONTENTS OF ADDRESS	NOTES
		1 1 00	[	]			$-\left(\frac{m}{L_\beta}V_{\beta 1}\right)$ @14
		01	2 0 0 0 0 0 0 0			1@2	
		02	x M 1 0 3 1				$\frac{mr_\beta}{L_\beta}$ @3
		03	x C 6 3 5 6		X	Imaginary Part	$\left\{\frac{mr_\beta}{L_\beta} i_{\beta 1}\right\}$ @12
		04	x U 1 1 3 7				
		05	[	]		$+m\phi$ @9	
		06	[	]		Real part	$\left\{+\frac{m^2\phi}{L_\alpha} i_{\beta 1}\right\}$ @21
		07	[	]	X	temp. stor.	
		08	[	]		temp. stor.	
		09	[	]		-Imaginary Part	$\left\{+\frac{m^2\phi}{L_\beta} i_{\alpha 1}\right\}$ @21
		10	x M 5 0 6 0			ϕ @9	
		11	x H 4 9 6 1		X		$-\frac{m^2\phi}{L_\beta}$ @12
		12	x U 1 1 2 8				
		13	[	]		-Real Part	$\left\{+\frac{m^2}{L_\beta}\phi i_{\alpha 1}\right\}$ @21
		14	x M 1 1 0 0				
		15	x C 1 0 4 4		X		
		16	x B 1 0 3 1				$\frac{mr_\beta}{L_\beta}$ @3
		17	x U 1 1 2 5				
		18	[	]		-imag. pt. (i_β, r_β) @9	
		19	2 0 0 0 0 0 0 0		X	1@2	
		20	x B 6 0 6 3				
		21	x C 1 1 0 7				
		22	x U 2 6 4 1				
		23			X		
		24	2 0 0 0 0 0 0 0				
		25	x M 5 0 1 1			real part $(i_{\beta 1})$ @9	
		26	x C 6 3 6 2			real part	$\left\{\frac{mr_\beta}{L_\beta} i_{\beta 1}\right\}$ @12
		27	x U 1 1 3 3		X		
		28	x M 5 0 0 7			real part $(i_{\alpha 1})$ @9	
		29	x U 1 1 5 1				
		30	[	]			$-\frac{m^2}{L_\beta}$ @3
		31	4 0 0 0 0 0 0 0		X	1@1 (HEX)	

CONDITIONAL STOP CODE X CARRIAGE RETURN

PROG NO _____ PREP BY _____ CK'D. BY _____ DATE _____

M _____ TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP.	ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		1 1 32	[	]			$-\frac{m^2}{4\rho}$ @3
		33	X B 5 0 1 2			Imaginary Part	$(i_{\beta 1})$ @9
		34	X U 1 1 0 2				
		35	X A 1 1 0 7		☒	-real part	$\{j m i_{\beta 1} \phi e^{j\phi}\}$ @19
		36	X U 1 1 5 4				
		37	X B 0 9 5 9			cos ϕ @1	
		38	X C 6 3 2 2				
		39	X U 1 1 4 0		☒		
		40	X B 1 0 0 5			sin ϕ @1	
		41	X C 6 3 1 1				
		42	X R 6 0 3 0				$\frac{m}{4\rho} i_{\beta 1} r_\rho e^{j\phi}$ @13
		43	X U 6 0 3 5		☒		
		44	X B 1 1 3 0				$-\frac{m^2}{4\rho}$ @3
		45	X U 1 1 1 0				
		46	X S 4 9 6 1				
		47	X M 5 0 0 8		☒		
		48	X C 1 1 1 3				
		49	X U 1 1 5 8				
		50	1 0 0 0 0 0 0 0				
		51	X C 1 1 0 9		☒		
		52	X U 1 1 4 6				
		53	[	]			$\frac{L_\beta}{L_\alpha L_\beta - m^2}$ @1
		54	X M 1 1 1 9			1@2	
		55	X A 1 1 1 3		☒	-Real Part	$\{j \frac{m^2}{L_\beta} \phi i_{\alpha 1}\}$ @21
		56	X N 1 2 0 0			1@27	
		57	X U 1 2 0 3				
		58	X B 6 3 1 6				
		59	X M 1 1 3 1		☒		
		60	X U 1 2 1 0				
		61	1 0 0 0 0 0 0 0			1@3	
		62					
		63	2 0 0 0 0 0 0 0		☒	1@2	

CONDITIONAL STOP CODE ☒ CARRIAGE RETURN

PROG NO PREP BY CHKD BY DATE

M TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP	ADDRESS	TYPE	CONTENT OF ADDRESS	NOTES
		1200		10		1@27	
		01	[	]			$\frac{L_\alpha}{L_\alpha L_\beta - m^2}$ @1
		02	80000000				
		03	xM1153		X		$\frac{L_\beta}{L_\alpha L_\beta - m^2}$ @1
		04	xC1219				
		05	xU1222				
		06	xA6335			imag. part $\{V_{\alpha 1} e^{j\omega_\alpha t}\}$ @10	
		07	xM1150		X	1@3	
		08	xU1220				
		09	40000000				
		10	xA6360			Real part $V_{\alpha 1} e^{j\omega_\alpha t}$ @10	
		11	xM1161		X	1@3	
		12	xA6063			Real part $\frac{m}{L_\beta} i_{\beta 1} r_\beta e^{j\phi}$ @13	
		13	xM1163			1@2	
		14	xU1215				
		15	xA1030		X	Real part $-\frac{m}{r_\beta} V_{\beta 1} e^{j(\omega_\beta t + \phi)}$	
		16	xM1202			1@4	
		17	xU1135				
		18	[	]			(1732)
		19	[	]	X	real part $(\dot{i}_{\alpha 1})$ @18	
		20	xA6015			imag. part $\frac{m}{L_\beta} i_{\alpha 1} r_\beta e^{j\phi}$ @13	
		21	xU1228				
		22	xB6358			- imag. part $(i_{\alpha 1} r_\alpha)$ @9	
		23	xM1209		X		
		24	xU1206				
		25	10000000				
		26	[	]		imag. $\{\dot{i}_{\alpha 1}\}$ @18	
		27	[	]	X	real $\{-jm\phi\, i_{\alpha 2} e^{j\phi}\}$ @19	
		28	xM1250			1@2	
		29	xA1044			-imag part $\{\frac{m}{L_\beta} V_{\beta 1} e^{j(\omega_\beta t + \phi)}\}$ @15	
		30	xM1252			1@4	
		31	xU1237		X		

CONDITIONAL STOP CODE CARRIAGE RETURN

PROG NO. PREP BY CK'D BY DATE

M TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP	ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
	☒						
		12 32	x S 5 0 1 1			real part $i_{\beta 1}$	@9
		33	X U 1 3 1 7				
		34					
		35				☒	
		36		1 0		1@27	
		37	x A 6 0 1 6				
		38	x M 1 1 2 4			1@2	
		39	x U 1 2 4 4			☒	
		40					
		41					
		42					
		43				☒	
		44	x A 1 1 0 9			- imag. part $\{ j \frac{m^2}{L_\beta} \phi i_{\alpha 1} \}$	@21
		45	x N 1 0 0 3			1@27	
		46	x U 1 3 0 3				
		47	x S 5 0 1 2			☒	
		48	x U 1 3 3 1				
		49					
		50	2 0 0 0 0 0 0 0				
		51	[	]		☒ imag. pt. $\{ i_{\alpha 1} r_\alpha \}$	@9
		52	8 0 0 0 0 0 0 0				
		53					
		54					
		55	[	]		☒ real part $\{ -\frac{m}{L_\alpha} V_{\alpha 1} e^{j(\omega_\alpha t - \phi)} \}$	@15
		56	4 0 0 0 0 0 0 0			1@1	
		57					
		58					
		59				☒	
		60	[	]		real part $V_{\beta 1} e^{j\omega_\beta t}$	@10
		61	2 0 0 0 0 0 0 0			1@2	
		62	[	]		imag. pt. $\{ j \frac{m^2}{L_\alpha} \phi \; i_{\beta 1} \}$	@21
		63	[	]		☒ $\frac{L_\beta}{L_\alpha L_\beta - m^2}$	@1

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☒ CONDITIONAL STOP CODE ☒ CARRIAGE RETURN

PROG NO PREP BY CK'D BY DATE

M TRACK

PROGRAM INPUT CODE	TAB	LOCATION	INSTRUCTION OP	INSTRUCTION ADDRESS	TAB	CONTENTS OF ADDRESS	NOTES
		1300	x	B6322		$\cos \omega_\beta t$ @1	
		01	x	U1336			
		02	[	]		temp. Storage.	
		03	x	M1153			$\frac{L_\beta}{L_\alpha L_\beta - m^2}$ @1
		04	x	C1226		imag part $\{i_{\alpha 1}\}$ @18	
		05	x	U2735			
		06		8000000			
		07	[	]		real part $\{j m \phi i_{\alpha 1} e^{-j\phi}\}$ @19	
		08		20000000			
		09	x	B0959		$\cos \phi$ @1	
		10	x	C6322			
		11	x	U1340			
		12	x	R6030			
		13	x	U6035			
		14	x	U1327			
		15	[	]			$\frac{m r_\beta}{L_\beta}$ @3
		16	[	]		$-\frac{m}{L_\alpha} V_{\alpha 1} \sin(\omega_\alpha t - \phi)$ @15	
		17	x	M5003		r_β @0	
		18	x	C1004			
		19	x	U1247			
		20	x	C6356			
		21	x	U1354			
		22	x	M5008		imag part $i_{\alpha 1}$ @9	
		23	x	C6362			
		24	x	U1312			
		25	x	B6311			
		26	x	U1343			
		27	x	B6063			
		28	x	C1307			
		29	x	U1357			
		30	[	]		imag pt $\{j m \phi i_{\alpha 1} e^{-j\phi}\}$ @19	
		31	x	M5003			

CONDITIONAL STOP CODE

CARRIAGE RETURN

PROG NO. _____ PREP BY _____ CK'D. BY _____ DATE _____

M _____ TRACK _____

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP.	ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		☒					
		13 32	x C 1 1 1 8				
		33	x U 1 3 0 9				
		34	8 0 0 0 0 0 0				
		35	[	]		☒	$\frac{m r_\alpha}{L_\alpha}$ @3
		36	x M 5 0 2 2			$Y_{\beta 1}$ @9	
		37	x C 1 2 6 0				
		38	x U 1 3 2 5				
		39	[	]		☒ imag. part	$\{ j \frac{m^2 \phi}{L_\phi} i_{\alpha 2} \}$ @21
		40	x S 1 0 0 5			$-\sin\phi$ @1	
		41	x C 6 3 1 1				$e^{-j\phi}$ @1 SET.
		42	x U 1 3 4 6				
		43	x M 5 0 2 2			☒	
		44	x C 1 3 0 2				
		45	x U 1 2 3 2				
		46	x S 5 0 6 1				BRING $m\phi$ @9
		47	x H 1 1 0 5			☒	Store $m\phi$ @9
		48	x U 1 3 4 9				
		49	x M 5 0 0 7			real part $i_{\alpha 1}$ @9	
		50	x U 1 3 2 0				
		51	4 0 0 0 0 0 0 0			☒	
		52	2 0 0 0 0 0 0 0				
		53	[	]			$-\frac{m r_\alpha}{L_\alpha}$ @3
		54	x S 1 1 0 5				
		55	x U 1 3 2 2			☒	
		56	[	]		imag. $(i_{\alpha 2})$ @18	
		57	x B 6 0 1 5				
		58	x C 1 3 3 0				
		59	x U 2 7 4 2			☒	
		60					
		61					
		62					
		63	[	]		☒	$-\frac{m V_{\alpha 2}}{L_\alpha}$ @14

CONDITIONAL STOP CODE ☒ CARRIAGE RETURN

PROG NO PREP BY CK'D BY DATE

PROGRAM

TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP	ADDRESS	STOP	CONTENT OF ADDRESS	NOTES
	1						
		1400	x B 1 0 2 9				$-\frac{mV_{\alpha 1}}{L\alpha}$ @14
		01	x U 1 4 3 6				
		02	[	]		real part $(i_{\beta 1})$ @18.
		03					
		04					
		05					
		06	x R 6 0 3 0				$-\frac{mr_\alpha i_{\alpha 1} e^{-j\phi}}{L\alpha}$
		07	x U 6 0 3 5				
		08	x B 0 9 5 1				
		09	x U 1 5 1 0				
		10					
		11					
		12					
		13					
		14	x B 1 0 2 9				$-\frac{mV_{\alpha 1}}{L\alpha}$ @14
		15	x U 1 4 2 5				
		16	2 0 0 0 0 0 0 0				
		17	x B 1 3 5 3				$-\frac{mr_\alpha}{L\alpha}$ @3
		18	x U 1 4 2 2				
		19	x S 1 0 0 5				$-\sin\phi$ @1
		20	x C 6 3 1 1				
		21	x U 1 4 0 6				
		22	x M 5 0 0 8				
		23	x C 6 3 5 6				
		24	x U 1 4 3 0				
		25	x M 6 3 2 2				
		26	x C 1 2 5 5				
		27	x U 1 4 0 0				
		28	x M 5 0 0 0				r_α @0
		29	x U 1 4 3 4				
		30	x B 0 9 5 9				cos ϕ @1
		31	x C 6 3 2 2				

CONDITIONAL STOP CODE

CARRIAGE RETURN

PROG NO _____ PREP BY _____ CK'D. BY _____ DATE _____

M _____ TRACK _____

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP.	ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		☒					
		14 32	x U 1 4 1 9				
		33	[	]		$\frac{m^2}{L\alpha}\phi$ @12	
		34	x C 1 0 5 6				
		35	x U 1 4 5 2		☒		
		36	x M 6 3 1 1				
		37	x C 1 3 1 6				
		38	x B 1 3 5 3				$-\frac{m}{L\alpha}r_\alpha$
		39	x U 1 4 4 2		☒		
		40	x A 1 2 5 5			real part $\{-\frac{m}{L\alpha}V_{\alpha 1}e^{j(\omega_\alpha t-\phi)}\}$ @15	
		41	x U 1 4 4 8				
		42	x M 5 0 0 7			real part $i_{\alpha 1}$ @9	
		43	x C 6 3 6 2		☒		
		44	x U 1 4 1 7				
		45	8 0 0 0 0 0 0 0			1 @4	
		46	2 0 0 0 0 0 0 0				
		47			☒		
		48	x M 1 3 3 4			1 @4	
		49	x A 1 3 0 7			real part $\{jm\phi i_{\alpha 1}e^{-j\phi}\}$ @19	
		50	x M 1 3 0 8				
		51	x U 1 5 2 0		☒		
		52	x S 5 0 1 0				
		53	x U 1 6 1 4				
		54	x M 5 0 1 2				
		55	x C 1 1 0 6		☒		
		56	x U 1 5 3 2				
		57	1 0 0 0 0 0 0 0				
		58	1 0 0 0 0 0 0 0				
		59	8 0 0 0 0 0 0		☒		
		60	x B 1 1 1 8			imag. pt. $\{-i_{\alpha 1}r_\alpha\}$ @9	
		61	x U 1 5 1 5				
		62	1 0 0 0 0 0 0 0			1 @3	
		63	x S 6 3 3 5			imag. part $V_{\alpha 1}e^{j\omega_\alpha t}$ @10	

CONDITIONAL STOP CODE ☒ CARRIAGE RETURN

PROG NO PREP BY CHKD BY DATE

PROGRAM

TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP ADDRESS	TOP	CONTENTS OF ADDRESS	NOTES
		1500	X U 1506			
		01	X A 1316			
		02	X M 1445		1 @4	
		03	X U 1508			
		04				
		05	[ ]			$\frac{L_\alpha}{L_\alpha L_\beta - m^2}$ @1
		06	X C 6335		$(V_{\alpha 1} = V_{\alpha 2})$	
		07	X U 1558			
		08	X A 1330			
		09	X U 2325			
		10	X M 5060		ϕ @9	
		11	X H 1433		$\frac{m^2}{L_\alpha}\phi$ @12	
		12	X U 1525			
		13	1000000		1 @7	
		14				
		15	X M 1351		1 @1	
		16	X A 1302		imaginary part $(V_{\beta 1} e^{j2\pi f_\beta t})$ @10	
		17	X U 1528			
		18	X S 1433		$-\frac{m^2}{L_\alpha}\phi$ @12	
		19	X U 1454			
		20	X A 1106		real part $\{j\frac{m^2}{L_\alpha}\phi\, i_{\beta 1}\}$ @21	
		21	X N 1236			
		22	X M 1201			$\frac{L_\alpha}{L_\alpha L_\beta - m^2}$ @1
		23	X C 1402			
		24	X U 1460			
		25	X M 5011			
		26	X C 1262		imag pt. $\{j\frac{m^2}{L_\alpha}\phi\, i_{\beta 1}\}$ @21	
		27	X U 1518			
		28	X M 1457		1 @3	
		29	X S 6015		imag. pt. $\{-\frac{mr_\alpha}{L_\alpha} i_{\alpha 1} e^{-j\phi}\}$ @13	
		30	X M 1352		1 @2	
		31	X U 1501			

CONDITIONAL STOP CODE

CARRIAGE RETURN

PROG NO ____ PREP BY ____ CK'D BY ____ DATE ____

TRACK ____

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP.	ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
	☒						
		1532	x	B1004			
		33	x	U1534			
		34	x	M1256		1@1	
		35	x	U1538		☒	
		36	4	0000000			
		37	[	]			(1758) (1742)
		38	x	A1260		real part $\{V_{\beta 1} e^{j\omega_\beta t}\}$ @10	
		39	x	M1225		☒ 1@3	
		40	x	U1541			
		41	x	S6063		real part $\{-\frac{m r_\alpha}{L_\alpha} i_{\alpha 1} e^{-j\phi}\}$ @13	
		42	x	U1543			
		43	x	M1101		☒ 1@2	
		44	x	U1440			
		45	8	0000000			
		46	x	N1032		1@27	
		47	x	M1505		☒	$\frac{L_\alpha}{L_\alpha L_\beta - m^2}$ @1
		48	x	C1063			
		49	x	Z0400		BREAK POINT 4	HALT IF SYMMETRICAL EXCITATION
		50	8	0 x T 1941		IF TRANSFER SWITCH DOWN, DO NOT COMPUTE NEGATIVE SEQ. COMPON.	
		51	x	U1463		☒	
		52	x	M5010			
		53	x	C1218			
		54	x	U1606			
		55	[	]		☒	$\frac{L_\beta}{L_\alpha L_\beta - m^2}$ @1
		56					
		57	2	0000000			
		58	x	S5009		real part $\{i_{d2}\}$ @9	
		59	x	U1428		☒	
		60	x	S2039			
		61	x	U1552			
		62		10			
		63				☒	

CONDITIONAL STOP CODE ☒ CARRIAGE RETURN

PROG NO PREP BY CK D BY DATE

EM TRACK

PROGRAM INPUT CODE	STOP	LOCATION	INSTRUCTION OP	ADDR	TAG	CONTENTS OF ADDRESS	NOTES
		1600	[	]			real part ($i_{\alpha 2}$) @18.
		01	X	S1044			
		02	X	C1044			
		03	X	B1039	X		$\frac{m r_\beta}{L_\beta}$ @3
		04	X	U1641			
		05	[	]			imag. $\{-\frac{m V_{\alpha 2}}{L_\alpha} e^{-j(\omega t - \phi)}\}$ @15
		06	X	B1056			
		07	X	M1536	X		
		08	X	U1617			
		09	[	]			real part $\{\frac{m r_\alpha}{L_\alpha} i_{\alpha 2} e^{j\phi}\}$ @13
		10					
		11	X	S5061	X		BRINGS $m\phi$ @9
		12	X	U1627			
		13	X	Z0405			
		14	X	M5000			
		15	X	C1251	X		
		16	X	U1611			
		17	X	A6360			
		18	X	U1619			
		19	X	M1462	X		1@3
		20	X	A6063			
		21	X	M1557			1@2
		22	X	U1658			
		23	X	M5009	X		
		24	X	C1339			
		25	X	U1560			
		26		10			
		27	X	M5013	X		real part ($i_{\beta 2}$) @9
		28	X	C6356			
		29	X	U1632			
		30	[	]			real $\{\frac{m V_{\alpha 2}}{L_\alpha} e^{-j(\omega t - \phi)}\}$ @15
		31	40000000		X		

CONDITIONAL STOP CODE CHARACTER RETURN

LGP-30 CODING SHEET

NO 2

PROG NO. PREP BY CK'D BY DATE

TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP.	ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		32	X	B5061		$-m\phi$ @9	
		33	X	U1635			
		34					
		35	X	M5014	☒	imag. part (i_{β_1}) @9	
		36	X	C6362			
		37	X	U1645			
		38	2	0000000			
		39	2	0000000	☒	imag. $\{\frac{m r_\alpha}{L_\alpha} i_{\alpha 2} e^{j\phi}\}$ @13	$-\frac{m^2}{L_\alpha}$ @3
		40	[	]			
		41	X	M5013			
		42	X	C6362			
		43	X	B1315	☒		$\frac{m r_\beta}{L_\beta}$ @3
		44	X	U1649			
		45	X	R6030			
		46	X	U6035			
		47	X	U1720	☒		
		48	[4	0000000]		1@1 (HEX.)	
		49	X	M5014			
		50	X	C6356			
		51	X	R6030	☒		
		52	X	U6035			
		53	X	B1132			$\frac{m^2}{L_\beta}$ @3
		54	X	U2259			
		55	8	0000000	☒	1@4	
		56					
		57	1	0000000			
		58	X	A1030		real part $\{-\frac{m}{L_\beta} V_{\beta 2} e^{-j(\omega_\beta t+\phi)}\}$ @15	
		59	X	M1545	☒	1@4	
		60	X	U1723			
		61	[	]			$\frac{L_\alpha}{L_\alpha L_\alpha - m^2}$ @1
		62	[	]		imag. ($i_{\alpha 2}$) @18	
		63			☒		

CONDITIONAL STOP CODE ☒ CARRIAGE RETURN

PROG NO PREP BY CK D BY DATE

EM TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP	ADDR	STOP	CONTENTS OF ADDRESS	NOTES
		1700	[	]			$\frac{m r_\alpha}{L_\alpha}$ @3
		01	XB	1251		$-\text{imag}\{i_{\alpha_1} r_\alpha\}$ @9	
		02	XM	1631		1@1	
		03	XU	1706	X		
		04					
		05					
		06	XA	6335		$\text{imag}(V_{\alpha 2} e^{-j\omega_\alpha t})$ @10	
		07	XM	1657	X	1@3	
		08	XU	1729			
		09	XM	1638			
		10	XA	1339		$\text{imag}\{j \frac{m^2 \phi'}{L_\beta} i_{\alpha 2}\}$ @21	
		11	XN	1626	X	1@27	
		12	XM	1555			$\frac{L_\beta}{L_\alpha L_\beta - m^2}$ @1
		13	XC	1356		$\text{imag}.(\dot{i}_{\alpha 2})$ @18	
		14	XU	1737			
		15	XA	1044	X	$\text{imag}\{-\frac{m}{L_\beta} V_{\beta 2} e^{-j(\omega_\beta t + \phi)}\}$ @15	
		16	XM	1459		1@4	
		17	XU	1742			
		18	[	]		$\text{imag}\{-j m \phi i_{\alpha 2} e^{j\phi}\}$ @19	
		19		2	X		
		20	XB	6063			
		21	XC	1756			
		22	XU	1757			
		23	XA	1756	X		
		24	XM	1446		1@2	
		25	XU	1732			
		26		10000			
		27	XS	5013	X		
		28	XU	1745			
		29	XA	6015			
		30	XM	1416		1@2	
		31	XU	1715	X		

CONDITIONAL STOP CODE

X CARRIAGE RETURN

PROG NO. PREP BY CK'D BY DATE

TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP.	ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		17 32	X A 1 2 1 8			real part $\{ j\frac{m^2}{L_\beta} \phi\, i_{\alpha 2} \}$	
		33	X N 1 5 6 2			1@27	
		34	X M 1 2 6 3				$\frac{-L_\beta}{L_\alpha L_\beta - m^2}$ @1
		35	X C 1 6 0 0				
		36	X U 1 7 0 1				
		37	X S 1 3 0 2				
		38	X C 1 3 0 2			$V_{\beta 2} = V_{\beta 1}$	
		39	X U 1 7 2 7				
		40	[	]			$\frac{L_\alpha}{L_\alpha L_\beta - m^2}$ @1
		41	2 0 0 0 0 0 0 0				
		42	X A 1 5 3 7			imag $\{ jm\phi\, i_{\beta 2}\, e^{-j\phi} \}$ @19	
		43	X U 1 7 0 9				
		44	2 0 0 0 0 0 0 0				
		45	X M 5 0 0 3			r_β	
		46	X C 1 5 0 4			real $\{ -r_\beta\, i_{\beta 2} \}$	@9
		47	X U 1 7 4 9				
		48	1 0 0 0 0 0 0 0				
		49	X S 5 0 1 4			imag. $\{ -i_{\beta 2} \}$	@9
		50	X M 5 0 0 3			r_β	
		51	X C 1 5 5 7			imaginary $\{ -i_{\beta 1} \cdot r_\beta \}$	@9
		52	X U 2 7 5 6				
		53	W W W W G Q 4				
		54					
		55					
		56	[	]			(1721)
		57	X B 6 0 1 5				
		58	X C 1 5 3 7				
		59	X U 1 6 0 1				
		60	2 0 0 0 0 0 0 0				
		61					
		62	[	]			$K \frac{p}{1} \frac{ABm}{746}$ @0
		63					

CONDITIONAL STOP CODE ☒ CARRIAGE RETURN

PROG NO PREP BY CK D BY DATE

LEM TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP	ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		1800	x	M6322			
		01	x	C1630		real $\{\frac{m}{L_\alpha} V_{\alpha 2} e^{-j(\omega_\alpha t - \phi)}\}$	
		02	x	U1816			
		03	x	C1718	X	imag $\{-jm\phi i_{\alpha 2} e^{j\phi}\}$ @19	
		04	x	B6063			
		05	x	C1227			
		06	x	B1335			$\frac{m r_\alpha}{L_\alpha}$
		07	x	M5009	X	real $\{i_{\alpha 2}\}$ @9	
		08	x	C6362		real $\{\frac{m r_\alpha}{L_\alpha} i_{\alpha 2}\}$ @12	
		09	x	U1842			
		10					
		11			X		
		12					
		13	x	B1363			$-\frac{m}{L_\alpha} V_{\alpha 2}$ @14
		14	x	U1825			
		15			X		
		16	x	B0959		cos ϕ @1	
		17	x	C6322			
		18	x	U1847			
		19			X		
		20	x	B1363			$-\frac{m}{L_\alpha} V_{\alpha 2}$ @14
		21	x	U1800			
		22	x	R6030			
		23	x	U6035	X		
		24	x	U1850			
		25	x	M6311			
		26	x	C1605			
		27	x	U1820	X		
		28	[	]		$-\frac{m^2}{L_\alpha}\phi$ @12	
		29	x	B6015			
		30	x	U1803			
		31	x	S5010	X	imag. ($i_{\alpha 2}$) @9	

CONDITIONAL STOP CODE X CARRIAGE RETURN

JO _____ PROG NO _____ PREP BY _____ CK'D. BY _____ DATE _____

BLEM _____ TRACK _____

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP	ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		☒					
		18 32	x M 5061			$-m\phi$ @9	
		33	x C 6362			real $\{-jm\phi i_{\alpha 2}\}$ @18	
		34	x R 6030				
		35	x U 6035		☒	$-jm\phi i_{\alpha 2} e^{j\phi}$ @19	
		36	x U 1829				
		37	x B 5009			real $(i_{\alpha 2})$ @9	
		38	x U 1839				
		39	x M 5061		☒	$-m\phi$ @9	
		40	x C 6356			imag. $\{jm\phi i_{\alpha 2}\}$ @18	
		41	x U 1831				
		42	x B 1700				$\frac{mr_\alpha}{L_\alpha}$ @3
		43	x M 5010		☒	imag $\{i_{\alpha 2}\}$	@9
		44	x C 6356				
		45	x U 1822				
		46	4 0 0 0 0 0 0 0				
		47	x B 1005		☒	$\sin\phi$	
		48	x C 6311				
		49	x U 1837				
		50	x B 6063				
		51	x C 1609		☒		
		52	x B 6015				
		53	x C 1639				
		54	x B 1640				$-\frac{m^2}{L_\alpha}$ @3
		55	x M 5060		☒		
		56	x H 1828				
		57	x M 5013				
		58	x C 6356				
		59	x U 1863		☒		
		60					
		61	2 0 0 0 0 0 0 0			1 @2	
		62	[	]		real part (i_{p2}) @18	
		63	x S 1828		☒		

C94183 MCBEE TORONTO CANADA

☒ CONDITIONAL STOP CODE ☒ CARRIAGE RETURN

PROG NO PREP BY CK'D BY DATE

EM TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP	ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		1900	XM	5014			
		01	XC	6362			
		02	XU	1904			
		03					
		04	XB	1504		$r_1\{-r_\beta i_{\beta 1}\}$ @9	
		05	XM	1648		1@1	
		06	XA	1260		real $\{V_{\beta 2} e^{-j\omega_\beta t}\}$ @10	
		07	XU	1908			
		08	XM	1458		1@3	
		09	XA	1609		real $\{\frac{m}{L_\alpha} r_\alpha i_{\alpha 2} e^{j\phi}\}$ @13	
		10	XM	1760		1@2	
		11	XA	1630			
		12	XM	1655		1@4	
		13	XA	1227		real $\{-j m\phi\, i_{\alpha 2} e^{j\phi}\}$	
		14	XU	1915			
		15	XM	1744		1@2	
		16	XA	6362		real $\{-j\frac{m^2}{L_\alpha}\phi\, i_{\beta 2}\}$ @21	
		17	XN	1403			
		18	XM	1740		$\frac{L_\alpha}{L_\alpha L_\beta - m^2}$ @1	
		19	XC	1862			
		20	XU	1922			
		21		F			
		22	XB	1557		imag. $\{-i_{\alpha 1} r_\alpha\}$ @9	
		23	XU	1924			
		24	XM	1846		1@1	
		25	XA	1302		imag. $\{V_{\beta 2} e^{-j\omega_\beta t}\}$ @10	
		26	XM	1748		1@3	
		27	XA	1639		imag $\{\frac{m r_\alpha}{L_\alpha} i_{\alpha 2} e^{j\phi}\}$ @13	
		28	XU	1932			
		29					
		30	XB	5007			
		31	XU	2019			

CONDITIONAL STOP CODE

CARRIAGE RETURN

PROG NO. PREP BY CK'D BY DATE

EM TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP.	ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		1 9 32	x M	1 8 6 1		1@2	
		33	x A	1 6 0 5		imag. $\{-\frac{m}{L_\alpha} V_{\alpha 2} e^{-j(\omega_\alpha t - \phi)}\}$ @15	
		34	x M	1 3 0 6		1@4	
		35	x A	1 7 1 8	☒	imag. $\{-j m \phi i_{\alpha 2} e^{j\phi}\}$ @19	
		36	x U	2 0 5 5			
		37					
		38	x N	1 6 1 0		1@27	
		39	x M	1 6 6 1	☒		$\frac{L_\alpha}{L_\alpha L_\beta - m^2}$ @1
		40	x C	1 6 6 2			
		41	x B	1 0 6 3		imag. $(i_{\beta 1})$ @18	
		42	x M	6 3 2 3		Δt @-9	
		43	x A	5 0 1 2	☒	imag. $(i_{\beta 1})$@9	
		44	x C	5 0 1 2			
		45	8 0 x T	1 9 5 1			
		46	x U	1 9 4 7			
		47	x B	1 6 6 2	☒	imag. $(i_{\beta 2})$ @18.	
		48	x M	6 3 2 3		Δt @-9	
		49	x A	5 0 1 4		imag. $(i_{\beta 2})$ @9	
		50	x C	5 0 1 4		imag. $(i_{\beta 2})$ @9	
		51	x B	1 4 0 2	☒	real $(i_{\beta 1})$@18	
		52	x M	6 3 2 3		Δt @-9	
		53	x A	5 0 1 1		real $(i_{\beta 1})$ @9	
		54	x C	5 0 1 1		real $(i_{\beta 1})$ @9	
		55	x U	2 0 0 4	☒		
		56					
		57					
		58					
		59				☒	
		60					
		61					
		62					
		63				☒	

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☒ CONDITIONAL STOP CODE

☒ CARRIAGE RETURN

LGP-30 CODING SHEET
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PROG NO PREP BY CK D BY DATE

EM TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP	ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		20 00					
		01					
		02					
		03					
		04	xB1219			real ($i_{\alpha 1}$)@18	
		05	xM6323			Δt @ -9	
		06	xA5007			real ($i_{\alpha 1}$) @9	
		07	xC5007				
		08	xU2012				
		09	wwwwwGQ4				
		10					
		11	61F8000			CHANGED TO 10^5 @19	
		12	80XT2040				
		13	xB1356			imag. ($i_{\alpha 2}$)@18	
		14	xM6323			Δt @ -9	
		15	xA5010			imag. ($i_{\alpha 2}$)@9	
		16	xC5010			imag. ($i_{\alpha 2}$) @9	
		17	xU2021				
		18	wwww8				
		19	xC6362				
		20	xU2037				
		21	xB1600			real ($i_{\alpha 2}$)@18	
		22	xM6323			Δt @ -9	
		23	xA5009			real ($i_{\alpha 2}$)@9	
		24	xC5009			real ($i_{\alpha 2}$) @9	
		25	xU2026				
		26	xB1862			real ($i_{\beta 2}$)@18	
		27	xM6323			Δt @ -9	
		28	xA5013			real ($i_{\beta 2}$) @9	
		29	xC5013			real ($i_{\beta 2}$) @9	
		30	xU2040				
		31	61F8000				

CONDITIONAL STOP CODE

CARRIAGE RETURN

PROG NO ____ PREP. BY ____ CK'D. BY ____ DATE ____

EM ____ TRACK ____

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP.	ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
	-						
	-	☒					
		2032	X	B5011			
		33	X	U2046			
		34	X	C6356			
		35	X	U2060		☒	
		36	[	]		10^5 @17	
		37	X	S5008			
		38	X	U2034			
		39	[	]		☒ $\frac{m^2\phi}{4\rho}$	
		40	X	B1226		imag. $\{i_{\alpha 1}\}$ @18	
		41	X	M6323		Δt @-9	
		42	X	A5008		imag. $\{i_{\alpha 1}\}$ @9	
		43	X	C5008		☒ imag. $\{i_{\alpha 1}\}$ @9	
		44	BOX	T1930			
		45	X	U2253			
		46	X	C6311			
		47	X	S5012		☒ imag. $(i_{\beta 1})$@9	
		48	X	U2050			
		49					
		50	X	C6322			
		51	X	R6030		☒ $j\, i_{\beta 1}, i_{\alpha 2}$ @18	
		52	X	U6035			
		53	X	U2300			
		54					
		55	X	M1741		☒ 1 @2	
		56	X	A6356		imag. $\{-j\frac{m^2\phi}{4\rho} i_{\beta 2}\}$ @21	
		57	X	U1938			
		58	X	B5009		real $\{i_{\alpha 2}\}$ @9	
		59	X	C6362		☒	
		60	X	B5011		real $\{i_{\beta 1}\}$@9	
		61	X	U2046			
		62					
		63				☒	

CONDITIONAL STOP CODE ☒ CARRIAGE RETURN

LGP-30 CODING SHEET
NO 1

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O PROG NO PREP BY CK'D BY DATE

EM TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP	ADDRESS	±	CONTENTS OF ADDRESS	NOTES
	-						
	-						
		21 00		2			
		01		11321J			
		02		4			
		03		xZ0001			
		04					
		05		61F8000			
		06		xC6356			
		07		xU2058			
		08					
		09		xZ0001			
		10					
		11					
		12		xB1762			$\frac{KPABm'}{746}$ @0
		13		xM6063			real part $\{f\, L_{\alpha 2}\, L_{\beta 1}\, e^{J\phi}\}$ @19
		14		xN1200			1@30
		15		xD5016			J@7
		16		xC5052			$\ddot{\delta}_{em}$ @11
		17		xB5053			$\dot{\delta}$ @9
		18		xM5018			K@0
		19		xA5017			R@9
		20		xM5053			$\dot{\delta}$ @9
		21		xD5016			J@7
		22		xC5058			
		23		xB5052			
		24		xS5058			
		25		xH5054			$\ddot{\phi}$ @11
		26		xM6323			Δt @-9
		27		xM1513			1@7
		28		xA5053			$\dot{\delta}$ @9
		29		xH5053			$\dot{\delta}$ @9
		30		xM6323			Δt @-9
		31		xU2328			

CONDITIONAL STOP CODE CARRIAGE RETURN

O ____ PROG NO ____ PREP BY ____ CK D. BY ____ DATE ____

EM ____ TRACK ____

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP.	ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		☒					
		21 32					
		33					
		34	X	S1613		xZ0405	
		35	X	C5763		☒	
		36	X	R2233			
		37	X	U2215			
		38	X	P1624			
		39	X	Z0025		☒	
		40	X	A1726		1@11	
		41	X	R2233			
		42	X	U2216			
		43	X	P1629		☒	
		44	X	Z0030			
		45	X	B5054		δ̈ @9 (NOW @11)	
		46	X	M2011		10^5 @19	
		47	X	R5559		☒	
		48	X	U5753			
		49	X	R2241			
		50	X	U2237			
		51	X	B5053		☒ δ́	
		52	X	M2031			
		53	X	R5559			
		54	X	U5753			
		55	X	R2241		☒	
		56	X	U2255			
		57	X	U2348			
		58					
		59	X	B2009		☒	
		60	X	C5763			
		61	X	R2241			
		62	X	U2237			
		63	X	U3307		☒	

CHARLES MCBEE TORONTO CANADA

☒ CONDITIONAL STOP CODE ☒ CARRIAGE RETURN

PROG NO _____ PREP BY _____ CK D BY _____ DATE _____

EM _____ TRACK _____

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP	ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		☒					
		2200					
		01					
		02					
		03	X	B 17 53		☒	
		04	x	C 57 63			
		05	x	R 22 41			
		06	x	U 22 37			
		07	x	B 63 31		☒	
		08	x	M 22 58			
		09	x	R 55 59			
		10	x	U 57 53			
		11	x	U 24 45		☒	
		12	x	B 63 31			
		13	x	U 09 49			
		14					
		15	x	B 21 01		☒	
		16	x	H 22 46			
		17	x	A 21 03			
		18	x	C 22 51			
		19	x	R 22 50		☒	
		20	x	U 22 46			
		21	x	R 22 41			
		22	x	U 22 37			
		23	x	P 50 09		☒	
		24	x	Z 00 10			
		25	x	P 03 11			
		26	x	Z 00 12			
		27	x	R 22 50		☒	
		28	x	U 22 51			
		29	x	R 22 41			
		30	x	U 22 35			
		31	x	B 22 46		☒	

C 9415 MCBEE ORIENT CANADA

☒ CONDITIONAL STOP CODE

☒ CARRIAGE RETURN

PROG NO. PREP BY CK'D BY DATE

EM TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP.	ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
	☒						
		22 32	x S 2018			wwww8	(1@11 - 2@29)
		33	x T [0000]				
		34	x U 2216				
		35	x B 1921		☒		
		36	x U 2238				
		37	x B 2109				
		38	x P 0323				
		39	x Z 0025		☒		
		40	x S 1719				
		41	T [0000]			EXIT	
		42	x U 2238				
		43			☒		
		44					
		45					
		46	[ ] B [ ]				
		47	x M 2105		☒		HEX: 61F8000
		48	x R 5559			MR. CLYDE OVENS' 20 CH./SEC.	
		49	x U 5753			OUTPUT SUBROUTINE.	
		50	U [0000]				
		51	[ ] B [ ]		☒		
		52	x U 2247				
		53	x B 5010			imag. {iαz}@9	
		54	x U 2106				
		55	x Z 0841		☒		
		56	x U 2237				
		57					
		58	[ ]			10^2 @9	
		59	x M 5060		☒		
		60	x H 2039				
		61	x U 1623				
		62					
		63			☒		

C941-3 MCBEE TORONTO CANADA

☒ CONDITIONAL STOP CODE ☒ CARRIAGE RETURN

PROG NO PREP BY CK'D BY DATE

EM TRACK

PROGRAM INPUT CODE	STOP	LOCATION	INSTRUCTION OP	ADDRESS	TAB	CONTENTS OF ADDRESS	NOTES
		23 00	x B 6015			$\text{mag}\,(j\,i_{\beta 1}, i_{\alpha 2})$ @18	
		01	x U 2306				
		02					
		03					
		04					
		05	w w w w w 6 0 0				
		06	x C 6356			$\text{mag}\,(j\,i_{\beta 1}, i_{\alpha 2})$ @18	
		07	x U 2309				
		08					
		09	x B 0959				
		10	x C 6322				
		11	x U 2319				
		12					
		13	x B 6063				
		14	x C 6362				
		15	x R 6063				
		16	x U 6035				
		17	x U 2112				
		18					
		19	x B 1005				
		20	x C 6311				
		21	x U 2313				
		22	4 0 0 0 0 0 0 0				
		23					
		24					
		25	x M 1261				
		26	x A 1262				
		27	x U 1546				
		28	x C 3558				M_8
		29	x B 2308				
		30	x C 3556				
		31	x R 3532				

CONDITIONAL STOP CODE

CARRIAGE RETURN

PROG NO PREP BY CK'D BY DATE

EM TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP.	ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
	'				'		
	'	☒			'		
		23 32	X	U 3736	'	NORMALIZE	Δδ
		33	X	R 2624	'		SET $K_3 = K_1$
		34	X	U 2620	'		
		35	X	R 2556	'	☒	FLOATING ADDITION
		36	X	U 2550	'		
		37	X	B 3558	'		
		38	X	C 5015	'		
		39	X	B 3556	'	☒	
		40	X	H 2431	'		
		41	X	U 2344	'		
		42			'		
		43			'	☒	
		44	X	B 5059	'	ϕ	
		45	X	A 5053	'	δ	
		46	X	C 5060	'		
		47	X	U 2134	'	☒	
		48	X	B 2363	'		
		49	X	C 5763	'		
		50	X	B 5015	'	δ	
		51	X	M 2323	'	☒ 10^9@30	
		52	X	R 5559	'		
		53	X	U 5753	'		
		54	X	B 2305	'		
		55	X	C 5763	'	☒	
		56	X	B 2431	'		
		57	X	M 2322	'		
		58	X	R 5559	'		
		59	X	U 5753	'	☒	
		60	X	U 2159	'		
		61			'		
		62			'		
		63	W W W W W W	K 4	'	☒	

CYCLE-TYPE MCBEE FORMS ANA-A

☒ CONDITIONAL STOP CODE

☒ CARRIAGE RETURN

PROG NO , PREP BY CK'D BY DATE

EM TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP	ADDRESS	TOP	CONTENT OF ADDRESS	NOTES
		2400					
		01	x B 2451			-3@29	
		02	x C 3550				$E_1 = -3$
		03	x C 3557				$M_1 = 0$
		04	x U 2406				
		05					
		06	x B 2456				.2 @0
		07	x C 3554				$M_2 = .2$
		08	x B 2451			-3@29	
		09	x C 3551				$E_2 = -3$
		10	x R 3532				FLOATING ADDITION
		11	x U 4448				SUBROUTINE
		12	x U 2413				
		13	x B 3556			(M_3 & E_3	E_3
		14	x C 2452			TO BE SAVED)	$E_T = E_3$
		15	x B 3558				M_3
		16	x C 2450				$M_T = M_3$
		17	U [0000]			(EXIT)	
		18					
		19					
		20					
		21	x B 2450				
		22	x C 3557				
		23	x B 2452				
		24	x C 3550				
		25	x U 2406				
		26					
		27					
		28	x B 2450			M_T	
		29	x C 3557				$M_1 = M_T$
		30	U [0000]			(EXIT)	
		31	[	]		E_δ @29	E_δ

CONDITIONAL STOP CODE

CARRIAGE RETURN

LGP-30 CODING SHEET

NO. 2

PAGE ____ OF ____

PROG NO. ____ PREP BY ____ CK D BY ____ DATE ____

EM ____ TRACK ____

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP	ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
	'				'		
	' ☒				'		
		24.32			'		
		33			'		
		34			'		
		35			' ☒		
		36	x B 3 5 5 8		'		$m_3 = m_\beta$
		37	x R 4 4 4 4		'		
		38	x U 4 2 1 5		'		
		39	x U 0 9 3 6		' ☒		
		40	x R 2 4 1 7		'		INITIALIZES
		41	x U 2 4 0 1		'		FLOATING POINT TIME
		42	x U 0 9 4 9		'		
		43	x Z 0 0 0 3		' ☒		$E\omega_p$
		44			'		
		45	x Z 1 6 3 1		'		
		46	x Z 0 8 3 2		'		
		47	x R 2 4 1 7		' ☒		
		48	x U 2 4 2 1		'		
		49	x U 2 5 4 5		'		
		50	[ ]		'		M_T @0
		51	W W W W W W W 4		' ☒		-3@29
		52	[ ]		'		E_T @29
		53			'		
		54			'		
		55			' ☒		
+0100000	'	56	20,00,00	0,00	'		.2@0
		57	x Z 0 0 0 3		'		$E\omega_a$
		58	x Z 0 0 0 2		'		
		59			' ☒		
		60			'		
		61			'		
		62			'		
		63			' ☒		

☒ CONDITIONAL STOP CODE

☒ CARRIAGE RETURN

LGP-30 CODING SHEET

NO 1

PAGE ____ OF ____

O ____ PROG NO ____ PREP BY ____ CK'D BY ____ DATE ____

LEM ____ TRACK ____

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP	ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
	-						
	-	☒					
		2500	[	]		$E\omega_\alpha t$	
		01	x	Z0003			$E\omega_\beta$
		02	x	B2452		E_T	
		03	x	C3550	☒		$E_1 = E_T$
		04	x	U2428			
		05	x	R2430			
		06	x	U2502			
		07	x	B2457	☒	$E\omega_\alpha = 3$	
		08	x	C3551			$E_2 = 3$
		09	x	U2519			
		10					
		11			☒		
		12					
		13	x	B3556		$E_3 = E_\phi$	
		14	x	R4234			
		15	x	U4253	☒		
		16	x	U2436			
		17	x	Z0003			$E\omega_\alpha$
		18					
		19	x	B5005	☒	$M\omega_\alpha$	
		20	x	C3554			
		21	x	R4144			
		22	x	U4440			
		23	x	U2513	☒		
		24					
		25					
		26					
		27	x	B3556	☒	E_3	
		28	x	C2500			$E\omega_\alpha t = E_3$
		29	x	B3558			
		30	x	C3659			
		31	x	U0928	☒		

C94155 M BEE TOR NT LAVAL A

☒ CONDITIONAL STOP CODE

☒ CARRIAGE RETURN

PROG NO. PREP BY CK'D BY DATE

EM TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP.	ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		☒					
		25 32					
		33					
		34	X	B 5006		$M\omega_\beta$	
		35	X	C 3557	☒		$M_1 = M\omega_\beta$
		36	X	B 2501		$E\omega_\beta$	
		37	X	C 3550			$E_1 = E\omega_\beta$
		38	X	B 2517		$E\omega_\alpha$	
		39	X	C 3551	☒		$E_2 = E\omega_\alpha$
		40	X	S 5005		$M\omega_\alpha$	
		41	X	C 3554			$M_2 = -M\omega_\alpha$
		42	X	R 3532			FLOATING ADDITION
		43	X	U 4448	☒		SUBROUTINE
		44	X	U 2563			
		45	X	P 1631			
		46	X	Z 0032			
		47	X	P 1632	☒		
		48	X	U 2212			
		49					
		50	X	B 5015			
		51	X	C 3554	☒		
		52	X	B 2431			
		53	X	C 3551			
		54	X	R 3532			
		55	X	U 4448	☒		
		56		U [0000]			
		57	[	]		$E\phi$	
		58					
		59	[	]	☒	$M\phi$	
		60					
		61					
		62					
		63	X	B 3556	☒	E_3	

CONDITIONAL STOP CODE ☒ CARRIAGE RETURN

PROG NO PREP BY CK'D BY DATE

EM TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP ADDRESS	CONTENT OF ADDRESS	NOTES
		26 00	x C 3550		
		01	x U 2606		
		02	[ ]	$\cos(\omega_\alpha t - \phi)$ @1	
		03			
		04	x C 3554		
		05	x U 2707		
		06	x B 3558	M_3	
		07	x C 3557		$M_1 = M_3$
		08	x U 2614		
		09	x R 2624		SET RETURN ADDRESS OF COPY SUBROUTING
		10	x U 4440		FLOATING MULTIPLY
		11	x R 2556		COMPUTE $(2\pi)(f_\beta - f_\alpha)t + \delta_0$
		12	x U 2550		IN FLOATING POINT.
		13	x U 2759		
		14	x B 2450	M_T	
		15	x C 3554		$M_2 = M_t$
		16	x B 2452	E_T	
		17	x C 3551		$E_2 = E_T$
		18	x R 4144		SET RETURN ADDRESS OF FLOATING MULTIPLY
		19	x U 2609		
		20	x B 3556	E_3	
		21	x C 3550		$E_1 = E_3$
		22	x B 3558	M_3	
		23	x C 3557		$M_1 = M_3$
		24	U [0 0 0 0]		
		25			
		26			
		27			
		28			
		29	x R 4444		$e^{j\phi}$ @1
		30	x U 4215		
		31	U [0 0 0 0]		

CONDITIONAL STOP CODE CARRIAGE RETURN

LGP-30 CODING SHEET
NO 2

PROG NO PREP BY CK'D BY DATE

EM TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP	ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		26 32					
		33					
		34					
		35					
		36	x B	3558			
		37	x U	2629			
		38					
		39					
		40					
		41	x B	3556		E_3	
		42	x C	2557			E_ϕ saved
		43	x B	3558		M_3	
		44	x C	2559			M_ϕ saved
		45	x U	1036			
		46	x B	6311			
		47	x C	2733			
		48	x U	1414			
		49					
		50					
		51	x R	2430			set t
		52	x U	2502			
		53	x U	2655			
		54					
		55	x B	5006		$m\omega_p$	
		56	x C	3554			$m_2 = m\omega_p$
		57	x B	2443		$E\omega_p$	
		58	x C	3551			$E_2 = E\omega_p$
		59	x R	4144			FLOATING MULTIPLY
		60	x U	4440			
		61	x R	2624			$E_1 = E_3$; $M_1 = M_3$
		62	x U	2620			
		63	x U	2716			

CONDITIONAL STOP CODE

CARRIAGE RETURN

O _____ PROG NO _____ PREP BY _____ CK D BY _____ DATE _____

LEM _____ TRACK _____

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		27 00				
		01				
		02				
		03	x R 4234			
		04	x U 4253			
		05	x U 2636			
		06				
		07	x B 2557			
		08	x C 3551			
		09	U [0000]			
		10				
		11	x S 2733			
		12	x C 6311			
		13	x U 1813			
		14	x B 3557			
		15	x U 2629			
		16	x B 2559			
		17	x R 2709			
		18	x U 2604			
		19	x R 3532			
		20	x U 4448			
		21	x R 2631			
		22	x U 2727			
		23	x U 1049			
		24				
		25				
		26				
		27	x B 3556			
		28	x U 2703			
		29				
		30	x S 2559			- Mφ
		31	x C 3554			

CONDITIONAL STOP CODE

CARRIAGE RETURN

LGP-30 CODING SHEET
NO 2

PROG NO PREP BY CK'D BY DATE

EM TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP.	ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		☒					
		27 32	x U	4448			
		33	[	]		$\sin(\omega_\alpha t - \phi)$ @1	
		34					
		35	x B	3550		☒ $E_{\omega_\alpha t}$	
		36	x R	4234			
		37	x U	4253			
		38	x R	2631			
		39	x U	2714		☒	
		40	x U	1300			
		41					
		42	x B	2500		$E_{\omega_\alpha t}$	
		43	x C	3550		☒	
		44	x B	3659		$M_{\omega_\alpha t}$	
		45	x C	3557			
		46	x R	3532			
		47	x U	2730		☒	
		48	x R	2631			
		49	x U	2727			
		50	x B	6322			
		51	x C	2602		☒	
		52	x U	2646			
		53					
		54					
		55				☒	
		56	x B	2602			
		57	x C	6322			
		58	x U	2711			
		59	x R	2631		☒	
		60	x U	2727			
		61	x U	1022			
		62					
		63				☒	

C-41-53 M. BEE T.R. N°C. CANADA

☒ CONDITIONAL STOP CODE

☒ CARRIAGE RETURN

LGP-30 CODING SHEET
NO. 1

NO _____ PROG NO _____ PREP BY _____ CK D BY _____ DATE _____

LEM _____ TRACK _____

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP	INSTRUCTION ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		☒					
		33 00					
		01					
		02	4	00000000			
		03				☒	
		04					
		05					
		06					
		07	x	B3357		☒	
		08	x	C5763			
		09	x	B2559			
		10	x	M3360			
		11	x	R5559		☒	
		12	x	U5753			
		13	x	B3363			
		14	x	C5763			
		15	x	B2557		☒	
		16	x	M3302			
		17	x	R5559			
		18	x	U5753			
		19	x	U2203		☒	
		20					
		21					
		22					
		23				☒	
		24					
		25					
		26					
		27				☒	
		28					
		29					
		30					
		31				☒	

C94185 McBEE TORONTO CANADA

☒ CONDITIONAL STOP CODE

☒ CARRIAGE RETURN

LGP-30 CODING SHEET

NO 2

O ____ PROG NO ____ PREP BY ____ CK D BY ____ DATE ____

LEM ____ TRACK ____

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP	INSTRUCTION ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
	'				'		
	'	☒			'		
		33 32			'		
		33			'		
		34			'		
		35			'	☒	
		36			'		
		37			'		
		38			'		
		39			'	☒	
		40			'		
		41			'		
		42			'		
		43			'	☒	
		44			'		
		45			'		
		46			'		
		47			'	☒	
		48			'		
		49			'		
		50			'		
		51			'	☒	
		52			'		
		53			'		
		54			'		
		55			'	☒	
		56			'		
		57	W W W W W W K 4		'		
		58			'		
		59			'	☒	
		60	7 7 3 5 9 4 0 0		'	10^9 @30	
		61			'		
		62			'		
		63	W W W W W 6 0 0		'	☒	

CONDITIONAL STOP CODE ☒ CARRIAGE RETURN

JOB NO PROG NO PREP BY CK'D BY DATE

PROBLEM FLOATING POINT ARITHMETIC TRACK

PROGRAM INPUT	±	LOCATION	INSTRUCTION	±	CONTENTS OF ADDRESS	NOTES
1 0 0 0 3 5 0 0						
; 0 0 0 3 5 0 0						
		35 00	B 0 0 5 0		E_1	
		01	S 0 0 5 1		E_2	$E_1 - E_2$
		02	T 0 0 1 0			Is $E_1 < E_2$
		03	S 0 0 5 3		10 @29	
		04	T 0 1 5 5			Is $E_1 < E_2 + 10$
		05	B 0 0 5 0		E_1	$E_1 \geq E_2 + 10$
		06	C 0 0 5 6		E_3	$E_3 = E_1$
		07	B 0 0 5 7		m_1	
		08	C 0 0 5 8		m_3	$M_3 = M_1$
		09	U 0 0 3 2			(EXIT)
		10	A 0 0 6 0		9@29	
		11	T 0 0 2 8			Is $E_2 > K_1 + 9$, $K_1 = E_1$
		12	A 0 0 6 2		Z0033	$E_2 < K_1 + 9$, $K_1 = E_1$
		13	Y 0 0 1 5			
		14	B 0 0 5 7		m_1	
		15	M[0 0 0 0]		$10^{-(E_2 - E_1)}$	
		16	C 0 0 5 7			
		17	B 0 0 5 1		E_2	
		18	C 0 0 5 6		E_3	$E_3 = E_2$
		19	U 0 1 0 7			
		20	A 0 0 6 3		Z0041	$E_1 > E_2$
		21	Y 0 0 2 3			
		22	B 0 0 5 4		m_2	
		23	M[0 0 0 0]		$10^{-(E_1 - E_2)}$	
		24	C 0 0 5 4			
		25	B 0 0 5 0		E_1	
		26	C 0 0 5 6		E_3	$E_3 = E_1$
		27	U 0 1 0 7			
		28	B 0 0 5 4		m_2	$E_2 > K_1 + 9$
		29	C 0 0 5 8		m_3	$M_3 = M_2$
		30	B 0 0 5 1		E_2	
		31	C 0 0 5 6		E_3	$E_3 = E_2$

CONDITIONAL STOP CODE — CARRIAGE RETURN

LGP-30 CODING SHEET

NO 2

O. _____ PROG NO _____ PREP BY _____ CK'D BY _____ DATE _____

EM _____ TRACK _____

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP.	INSTRUCTION ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		32	U	[0 0 0 0]			EXIT FROM FLOATING ADDITION
		33		2			
		34		16			
		35		K 6			
		36		8 6 4			
		37		5 3 Q 2			
		38		3 4 6 K J			
		39		2 0 J 4 9 J			
		40		1 4 7 F Q 1 4			
		41		J J J J J J J			
		42		1 4 7 F Q 1 4			
		43		2 0 J 4 9 J			
		44		3 4 6 K J			
		45		5 3 Q 2			
		46		8 6 4			
		47		K 6			
		48		1 6			
		49		2			
		50	[	]			E_1 @29
		51	[	]			E_2 @29
		52	4 0 0 0 0 0 0 0				
		53		x Z 0 0 1 0			
		54	[	]			M_2 @0
		55	4 0 0 0 0 0 0 0				
		56	[	]			E_3 @29
		57	[	]			M_1 @0
		58	[	]			M_3 @0
		59	4 0 0 0 0 0 0 0				
		60		x Z 0 0 0 9			
		61	4 0 0 0 0 0 0 0				
		62		Z 0 0 3 3			
		63		Z 0 0 4 1			

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CONDITIONAL STOP CODE

CARRIAGE RETURN

LGP-30 CODING SHEET
NO 1

PROG NO PREP BY CK'D BY DATE

PROBLEM TRACK

PROGRAM INPUT CODE	STOP	LOCATION	INSTRUCTION OP	INSTRUCTION ADDRESS	STOP	CONTENT OF ADDRESS	NOTES
		36 00	4	00000000			
		01	1	K7KJO		9×10^{-4} @0	
		02	A	0052			
		03	T	0135	X		
		04	U	0118			
		05	3	WWWWWWQ			
		06	x	Z0003			
		07	B	0057	X	M.	
		08	T	0102			
		09	S	0059		.5 @0	
		10	T	0118			
		11	C	0057	X		
		12	S	0162			C = C-1
		13	A	0163			
		14	C	0163			
		15	U	0118	X		
		16	x	Z0008			
		17	7	WWWWWWQ			
		18	B	0054			
		19	T	0140	X		
		20	S	0052			
		21	T	0132			
		22	R	0130			
		23	U	0128	X		
		24	S	0160			
		25	A	0163			
		26	C	0163			
		27	U	0213	X		
		28	A	0057			
		29	C	0058			
		30	U	[0000]			
		31			X		

CONDITIONAL STOP CODE

X CARRIAGE RETURN

LGP-30 CODING SHEET
NO 2

O. _____ PROG NO. _____ PREP BY _____ CK'D. BY _____ DATE _____

EM _____ TRACK _____

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP	INSTRUCTION ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		☒					
		36 32	A	0061			
		33	U	0149			
		34	XZ	0009			
		35	C	0057		☒	
		36	B	0158			
		37	U	0113			
		38					
		39	XZ	0005		☒	
		40	A	0055			
		41	T	0144			
		42	S	0100			
		43	U	0149		☒	
		44	C	0054			
		45	B	0160			
		46	A	0163			
		47	C	0163		☒	
		48	B	0054			
		49	R	0130			
		50	U	0128			
		51	U	0213		☒	
		52					
		53	4	0000000			
		54	4	0000000			
		55	A	0134		☒ $E_1 < E_2 + 10$ $E_1 = E_2$	$K_1 < K_2 + 10$ $K_1 = K_2$
		56	T	0025			
		57	U	0020			
		58	XZ	0001			
		59				☒	
		60	XZ	0001			
		61	XZ	0004			
		62	XZ	0001			
		63				☒	

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☒ CONDITIONAL STOP CODE

☒ CARRIAGE RETURN

LGP-30 CODING SHEET
NO 1

PROG NO PREP BY CK'D BY DATE

EM TRACK

PROGRAM INPUT CODE	STOP	LOCATION	INSTRUCTION OP	ADDRESS	STD	CONTENTS OF ADDRESS	NOTES
		37 00	A	0250			
		01	T	0032			
		02	S	0252			
		03	U	0926	X		
		04	A	0326			
		05	R	0342			
		06	U	0327			
		07	U	0032	X		
		08	B	0058			
		09	T	0233			
		10	S	0153			
		11	H	0058	X		
		12	U	0237			
		13	B	0163			
		14	T	0253			
		15	S	0158	X		
		16	T	0236			
		17	S	0160			
		18	T	0208			
		19	U	0243	X		
		20		F			
		21	S	0250			
		22	T	0204			
		23	U	0032	X		
		24	N	0139			
		25	C	0058			
		26	S	0162			
		27	A	0056	X		
		28	C	0056			
		29	U	0236			
		30	W	4240			
		31	X Z	0735	X		

CONDITIONAL STOP CODE

X CARRIAGE RETURN

LGP-30 CODING SHEET

NO 2

O _____ PROG NO PREP BY CK D. BY DATE

EM TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP.	ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		37 32	XZ	0001			
		33	A	0105			
		34	T	0338			
		35	U	0245	☒		
		36	B	0058			
		37	T	0200			
		38	S	0160			
		39	T	0032	☒		
		40	S	0326			
		41	T	0204			
		42	U	0032			
		43	B	0058	☒		
		44	T	0338			
		45	S	0117			
		46	C	0058			
		47	U	0236	☒		
		48	5W5Q	100			
		49					
		50	JJJJJJJ				
		51	JJJJJJJ		☒		
		52	JJJJJJJ				
		53	A	0232			
		54	T	0322			
		55	U	0308	☒		
		56		53Q2			
		57	XZ	0007			
		58		2			
		59	JJJJJJJ		☒		
		60	40000000				
		61		16			
		62		989680			
		63	40000000		☒		

C-94183 M TORONTO CANADA

☒ CONDITIONAL STOP CODE

☒ CARRIAGE RETURN

LGP-30 CODING SHEET
NO 1

PROG NO PREP BY CK'D BY DATE

EM TRACK

PROGRAM INPUT CODE	STOP	LOCATION	INSTRUCTION OP	INSTRUCTION ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		38 00	M	0250			
		01	A	0251			
		02	C	0058			
		03	B	0232	X		
		04	U	0227			
		05	R	0342			
		06	U	0327			
		07	U	0453	X		
		08	B	0058			
		09	T	0313			
		10	S	0260			
		11	T	0345	X		
		12	U	0300			
		13	A	0263			
		14	U	0346			
		15		530J	N		
		16					
		17	JJJJJJJ				
		18	JJJJJJJ				
		19		864	N		
		20	A	0056			
		21	U	0341			
		22	B	0058			
		23	T	0345	X		
		24	U	0300			
		25	xZ	0006			
		26	JJJJJJJ				
		27	S	0256	X		
		28	T	0350			
		29	S	0358			
		30	T	0436			
		31	S	0360	N		

CONDITIONAL STOP CODE

N CARRIAGE RETURN

LGP-30 CODING SHEET
NO 2

D _____ PROG NO _____ PREP BY _____ CK'D BY _____ DATE _____

EM _____ TRACK _____

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP	INSTRUCTION ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		38 32	T	0448			
		33	A	0362			
		34	N	0220			
		35	U	0343		☒	
		36	B	0058			
		37	T	0345			
		38	M	0317			
		39	S	0318		☒	
		40	U	0302			
		41	C	0056			
		42	U	[0000]			
		43	C	0058		☒	
		44	U	0348			
		45	A	0117			
		46	C	0058			
		47	U	0236		☒	
		48	S	0363			
		49	U	0320			
		50	A	0315			
		51	T	0416		☒	
		52	S	0231			
		53	T	0400			
		54	A	0319			
		55	N	0463		☒	
		56	C	0058			
		57	U	0404			
		58	207	068			
		59		J2		☒	
		60	126	Q978			
		61		16			
		62	147	FQ14			
		63	x	Z0001		☒	

CANADA MICRO TORONTO CANADA

☒ CONDITIONAL STOP CODE

☒ CARRIAGE RETURN

LGP-30 CODING SHEET
NO 1

PROG NO PREP BY CK D BY DATE

EM TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP	ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		39 00	A	0415		10^{-6} @0	
		01	N	0230		10^{6} @31	
		02	C	0058			
		03	U	0410	X		
		04	S	0433		5@29	
		05	A	0056			
		06	C	0056			
		07	U	0342	X		
		08	346	KJ			
		09	x Z	3904		10^{4} @31	
		10	S	0325			
		11	A	0056	X		
		12	U	0413			
		13	C	0056			
		14	U	0342			
		15		864	X		
		16	A	0359			
		17	T	0425			
		18	A	0261			
		19	N	0262	X		
		20	C	0058			
		21	S	0257			
		22	A	0056			
		23	C	0056	X		
		24	U	0342			
		25	A	0361		10^{-8}	
		26	N	0248		10^{8}	
		27	U	0429	X		
		28	200000000				
		29	C	0058			
		30	S	0116			
		31	A	0056	X		

CONDITIONAL STOP CODE

X CARRIAGE RETURN

LGP-30 CODING SHEET
NO 2

PROG NO PREP BY CKD BY DATE

M TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP.	INSTRUCTION ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
	-						
	-	☒					
		32	U	0434			
		33	xZ	0005			
		34	C	0056			
		35	U	0342		☒	
		36	A	0101		9×10^{-4} @0	
		37	T	0443			
		38	A	0460			
		39	N	0461		☒	
		40	C	0058			
		41	S	0106			
		42	U	0431			
		43	A	0408		☒ 10^{-4} @0	
		44	N	0409		10^{4} @31	
		45	C	0058			
		46	S	0161			
		47	U	0431		☒	
		48	A	0563		10^{-2} @0	
		49	N	0457		10^{2} @31	
		50	C	0058			
		51	S	0523		☒ 2 @29	
		52	U	0431			
		53	S	0058			
		54	C	0058			
		55	U	0032		☒	
		56					
		57		64			
		58					
		59	xZ	0002		☒	
		60	3	46KJ			
		61	xZ	0358			
		62					
		63	1	86F0		☒	

☒ CONDITIONAL STOP CODE ☒ CARRIAGE RETURN

LGP-30 CODING SHEET
NO 1

PROG NO PREP BY CK D BY DATE

M TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP	INSTRUCTION ADDRESS	TOP	CONTENTS OF ADDRESS	NOTES
		40 00	B	0050			
		01	A	0051			
		02	C	0056			
		03	U	0607			
		04	B	0054			
		05	T	0509			
		06	R	0639			
		07	U	0528			
		08	U	0514			
		09	R	0604			
		10	U	0600			
		11	C	0054			
		12	U	0514			
		13					
		14	B	0057			
		15	T	0519			
		16	R	0639			
		17	U	0528			
		18	U	0525			
		19	R	0604			
		20	U	0600			
		21	U	0525			
		22	x Z	0001			
		23	x Z	0002			
		24 [		]			temp Storage
		25	M	0054			
		26	C	0058			
		27	U	0950			
		28	S	0557			
		29	T	0536			
		30	S	0559			
		31	T	0542			

CONDITIONAL STOP CODE

CARRIAGE RETURN

LGP-30 CODING SHEET
NO 2

PROG NO PREP BY CK D BY DATE

PROGRAM

TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP.	INSTRUCTION ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		40 32	S	0561			
		33	T	0549			
		34	A	0556			
		35	U	0644		X	
		36	A	0558			
		37	N	0560			
		38	C	0524			
		39	B	0661		X	
		40	A	0562			
		41	U	0633			
		42	A	0428			
		43	N	0522		X	
		44	U	0545			
		45	C	0524			
		46	B	0611			
		47	A	0562		X	
		48	U	0633			
		49	A	0100			
		50	N	0258			
		51	U	0552		X	
		52	C	0524			
		53	B	0232			
		54	U	0612			
		55				X	
		56	40000000				
		57	10000000				
		58	10000000				
		59	10000000			X	
		60	XZ	0002			
		61	20000000				
		62					
		63	147	FQ14		X	

CONDITIONAL STOP CODE

X CARRIAGE RETURN

LGP-30 CODING SHEET
NO 1

PROG NO | PREP BY | CK'D BY | DATE

M | TRACK

	PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP	ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
1								
2								
3			41 00	M	0922			
4			01	R	0639			
5			02	U	0528			
6			03	M	0653	X		
7			04	U	[0000]			
8			05	J	JJJJJJJ			
9			06	x	Z0002			
10			07	B	0057	X		
11			08	M	0054			
12			09	T	0640			
13			10	U	0645			
14			11	x	Z0002	X		
15			12	A	0562			
16			13	U	0633			
17			14	x	Z0001			
18			15			X		
19			16					
20			17	J	JJJJJJJ			
21			18					
22			19	B	0562	X		
23			20	S	0606			2@29
24			21	T	0644			
25			22	S	0651			
26			23	T	0706	X		
27			24	S	0660			
28			25	T	0657			
29			26	A	0712			
30			27	Y	0630	X		
31			28	U	0629			
32			29	B	0058			
33			30	M	[0000]			
34			31	U	0643	X		

CONDITIONAL STOP CODE

X CARRIAGE RETURN

LGP-30 CODING SHEET
NO 2

PROG NO _____ PREP BY _____ CK'D BY _____ DATE _____

EM _____ TRACK _____

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP	INSTRUCTION ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		4 1 32					
		33	C	0562			
		34	U	0638			
		35					
		36	Z	0740			
		37					
		38	B	0524			
		39	U	[0000]			
		40	A	0605			
		41	T	0649			
		42	U	0504			
		43	C	0058			
		44	U	[0000]			
		45	S	0617			
		46	T	0504			
		47	A	0605			
		48	U	0643			
		49	S	0700			
		50	U	0643			
		51	x Z	0001			
		52					
		53	8	0000 0000			
		54					
		55					
		56	Z	0739			
		57	A	0636			
		58	Y	0709			
		59	U	0708			
		60	x Z	0001			
		61	x Z	0003			
		62					
		63					

C941 3 M[illegible] TORONTO CANADA

⊠ CONDITIONAL STOP CODE ⊠ CARRIAGE RETURN

LGP-30 CODING SHEET
NO 1

PROG NO PREP BY CK'D BY DATE

EM TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP	ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		42 00	J J J J J J J				
		01	8 0 0 0 0 0 0 0				
		02	5 0 0 0 0 0 0 0				
		03	2 8 0 0 0 0 0 0				
		04	1 4 0 0 0 0 0 0				
		05					
		06	A	0656		Z0739	
		07	Y	0709			
		08	B	0058			
		09	D	[0000]			
		10	U	0643			
		11					
		12	Z	0702			
		13					
		14					
		15	T	0719			
		16	R	0759			
		17	U	0748			
		18	U	0916			
		19	M	0762			
		20	R	0759			
		21	U	0748			
		22	M	0701			
		23	U	0916			
		24					
		25	R	0749			
		26	U	0760			
		27	U	0759			
		28	A	0743			
		29	Y	0853			
		30	S	0745			
		31	Y	0756			

CONDITIONAL STOP CODE

CARRIAGE RETURN

LGP-30 CODING SHEET

NO 2

O. PROG NO PREP BY CK'D BY DATE

LEM TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP.	ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		42 32	S	0747			
		33	Y	0748			
		34	U	[0000]			
		35					
		36	x Z	0008			
		37	6487	QK50		2π @3	
		38	33333332			.4 @0	
		39	66666666			.8 @0	
		40	S	0862			
		41	T	0842			
		42	U	0845			
		43	Z	0827			
		44					
		45	x Z	0009			
		46	Z	0800			
		47	x Z	0009			
		48	M	[0000]			
		49	U	[0000]			
		50	A	0736			
		51	T	0849			
		52	U	0725			
		53	T	0750			
		54	R	0749			
		55	U	0740			
		56	E	[0000]			
		57	U	[0000]			
		58	M	0737			
		59	U	[0000]			
		60	A	0746			
		61	U	0733			
		62	80000000				
		63					

C-941-3 M. HILL T. RUNT ANA. A

CONDITIONAL STOP CODE

CARRIAGE RETURN

LGP-30 CODING SHEET
NO 1

PAGE 17 OF 20

NO ____ PROG NO ____ PREP BY ____ CK'D BY ____ DATE ____

BLEM ____ TRACK ____

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP	ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		43 00	xZ	0001			
		01		1F			
		02		10F			
		03		F7J			
		04		68KJ			
		05		4189 4			
		06		28W5J2			
		07		199999F			
		08	1000	0000			
		09	65KG	W21F			
		10	7W52	QQF0			
		11	4W93	K524			
		12	6378	JF6J			
		13	7J56	WK08			
		14	4KG6	5Q24			
		15	6123	W5FQ			
		16	796J	W31F			
		17	4GQ4	17W0			
		18	3WWW	WWWQ			
		19	7WWW	WWQ			
		20	7W	WWWQ			
		21	W	WWWQ			
		22	1W	WWQ			
		23	1W	WQ			
		24	3W	Q			
		25	7	Q			
		26	6				
		27	2				
		28	xZ	0004			
		29	xZ	0100			
		30	xZ	0800			
		31	4	000			

CONDITIONAL STOP CODE

CARRIAGE RETURN

PROG NO. PREP BY CK'D BY DATE

EM TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP.	ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
	'				'		
	' ☒				'		
		4 3 3 2		4 0 0 0 0	'		
		3 3		2 0 0 0 0 0	'		
		3 4		1 0 0 0 0 0 0	'		
		3 5		1 0 0 0 0 0 0 0	'	☒	
		3 6		x Z 0 0 0 9	'		
		3 7		A 0 8 5 9	'		
		3 8		U 0 7 3 3	'		
		3 9			'	☒	
		4 0			'		
		4 1		x Z 0 0 0 1	'		
		4 2		R 0 7 4 9	'		
		4 3		U 0 8 3 7	'	☒	
		4 4		U 0 7 5 9	'		
		4 5		S 0 8 6 0	'		
		4 6		T 0 8 5 0	'		
		4 7		x Z 0 0 0 0	'	☒	
		4 8		x Z 0 0 0 0	'		
		4 9		x Z 0 0 0 0	'		
		5 0		A 0 8 3 6	'		
		5 1		R 0 7 5 7	'	☒	
		5 2		U 0 7 2 8	'		
		5 3		N 0 8 2 7	'		
		5 4		U 0 7 5 8	'		
		5 5			'	☒	
		5 6			'		
		5 7			'		
		5 8			'		
		5 9		Z 0 8 0 9	'	☒	
		6 0		x Z 0 0 0 9	'		
		6 1			'		
		6 2		x Z 0 0 0 1	'		
		6 3			'	☒	

C941-3 M. BEE TORONTO CANADA

☒ CONDITIONAL STOP CODE

☒ CARRIAGE RETURN

LGP-30 CODING SHEET
NO 1

PROG NO PRLP BY CK D BY DATE

EM TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP	ADDRESS	STOP	CONTENTS OF ADDRES	NOTES
		44 00	B	0050			START FLOATING
		01	S	0051			DIVISION
		02	A	0945			
		03	U	0906	X		
		04					
		05					
		06	C	0056			
		07	U	0909	X		
		08					
		09	B	0959		1@0 - 1@30	
		10	D	0054			
		11	C	0054	X		
		12	C	0562			
		13	U	0607			
		14	Z	0818			
		15	M	0958	X		
		16	x H	6345			
		17	U	0930			
		18					
		19			X		
		20					
		21					
		22	8	0000000			
		23	x B	6345	X		
		24	U	0937			
		25					
		26	M	0955			
		27	R	0342	X		
		28	U	0327			
		29	U	0453			
		30	R	1016			sin θ
		31	U	1000	X		

X CONDITIONAL STOP CODE

X CARRIAGE RETURN

LGP-30 CODING SHEET

NO 2

NO ____ PROG NO ____ PREP BY ____ CK'D BY ____ DATE ____

BLEM ____ TRACK ____

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP	ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		☒					
		44 32	x	C 6311			
		33		U 0923			
		34					
		35		C 0921		☒	
		36		U 0915			
		37		R 1016			
		38		U 1045			
		39		U 0943		☒	
		40		C 0562			
		41		U 0500			
		42					
		43	x	C 6322		☒	
		44		U [0000]			
		45	x	Z 0001			
		46					
		47				☒	
		48		C 0163			
		49		U 0000			
		50		B 0056			
		51		S 0614		☒	
		52		C 0056			
		53		U 0619			
		54					
		55	8 0000000			☒	
		56					
		57		Z 0856			
		58	9 G781290				
		59	J J J J J J F			☒	
		60		Z 0020			
		61		Z 0024			
		62		Z 0018			
		63		Z 0010		☒	

C 94193 MCBEE TORONTO CANADA

☒ CONDITIONAL STOP CODE

☒ CARRIAGE RETURN

LGP-30 CODING SHEET
NO 1

NO — PROG NO PREP BY CK'D BY DATE

LEM COMPLEX NUMBERS MULTIPLICATION TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		60 00	X B 6322			
		01	U 0006			
		02				
		03		X		
		04				
		05				
		06	X M 6356			
		07	C 0043	X		
		08	U 0019			
		09				
		10				
		11		X		
		12	X S 1162			
		13	C 0063			
		14	U 0000			
		15		X		
		16				
		17				
		18				
		19	X B 6362	X		
		20	U 0032			
		21				
		22				
		23		X		
		24				
		25	X M 6311			
		26	X C 1162			
		27	U 0047	X		
		28	A 0043			
		29	C 0015			
		30	U [0000]			(EXIT)
		31		X		

X CONDITIONAL STOP CODE

X CARRIAGE RETURN

NO 2

PAGE 2 OF 2

O. PROG NO. PREP BY CK'D BY, DATE

LEM TRACK

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP.	ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		60 32	x M 6 3 1 1				
		33	U 0 0 2 8				
		34					
		35	x B 6 3 5 6			☒	
		36	U 0 0 2 5				
		37					
		38					
		39				☒	
		40					
		41					
		42					
		43				☒	
		44					
		45					
		46					
		47	x B 6 3 6 2			☒	
		48	U 0 0 5 0				
		49					
		50	x M 6 3 2 2				
		51	U 0 0 1 2			☒	
		52					
		53					
		54					
		55				☒	
		56					
		57					
		58					
		59				☒	
		60					
		61					
		62					
		63				☒	

COPYRIGHT MCBEE TORONTO CANADA

☒ CONDITIONAL STOP CODE ☒ CARRIAGE RETURN

APPENDIX B

OPERATING PROCEDURE

Stage A:

Before depressing the "Power On" button the following checks should be made:

(1) The "input selector" switch should be to "typewriter".

(2) The "output selector" switch should be to "typewriter".

(3) "Reader Power" should be up.

(4) "Punch Power" should be up.

(5) On the consul

(a) the "manual" button should be down.

(b) the button between "Standby" and "Operate" must be depressed.

(c) all breakpoints, the six bit input switch and the transfer control switch must be up.

(d) the "execute" button must be up. The LGP 30 at University of Alberta has a tendency for this button to stick.

Stage B:

After the checks of Stage A have been completed the operator may depress "power on" switch. When the "operate" light appears the operator may proceed to Stage C.

Stage C:

(1) The operator should turn flexowriter power "on" and

the "reader power" button should be depressed.

(2) The flexowriter connector switch should be off and the manual input lever on the flexowriter should be down. All other levers on the flexowriter should be up.

(3) Paper tape number 1 should be inserted in the flexowriter mechanical reader.

(4) The operator should depress the "Start Read" lever. This will result in C3Q00' being typed and being read into the accumulator.

(5) The operator should depress "Fill Instruction" on consul. This would result in an order being placed into the instruction register namely an order to clear the contents of the accumulator into track 62 sector 00.

(6) The operator should depress "start read". The result would be I00J8 being typed and read into the accumulator.

(7) The operator should depress "one operation", "execute instruction", and "manual" buttons in that order. The "one operation" puts the computer into a mode where the "execute instruction" can be effective and the instruction filled in stage C(4) clears an instruction (input) into track 62 sector 00.

(8) Stages C(4), C(5), C(6) and C(7) should be repeated until the instruction U3Q00' has been loaded. The instruction which loads U3Q00' is H3Q10' which means store the contents of the cumulator (U3Q00') in track 62 sector 04. The accumulator will retain U3Q00.

(9) Depressing "Fill Instruction" will place the instruction

U3Q00 into the instruction register and such will be necessary.

(10) The operator should depress "one operation", "execute instruction" and "manual".

(11) The operator should depress "Reader Stop" and insert tape number 2 into the photoreader, turn the "Input Selector Switch" to "photoreader".

(12) The operator should depress "One Operation", "Normal" and "Start" on the consul. The result should be that the computer should load a paper tape program.

(13) The computer will stop without having taken all of the program. The remainder will be composed of two parts: a portion, in hexadecimal, self loading in track 06 and a portion in binary-coded decimal which will be relocatable.

(14) When the operator presses "start" on the consul the computer will load more program into track 06 and halt. The remainder of the tape should be of no consequence to this paper.

(15) The operator should insert tape number three into the photoreader and depress the "start" button. The computer will stop near the end of the tape. If the operator should desire to study the doubly-excited induction machine with artificial damping torques he should remove the program tape. If he wishes to study the doubly-excited induction machine without artificial he should depress "start".

(16) The operator should insert an appropriate data tape in the photoreader and press "start".

(17) The operator should insert a quantity of paper tape in

the punch, depress all break points and, if a symmetrical excitation is to be studied, the transfer control button should also be depressed.

(18) The last "word" on the data tape should be .0000942'. The punch power should be on. The operator should then depress the "start" button. After the computer commences punching, the operator should turn the input selector switch to typewriter. Then the operator should turn off the "reader power" and the flexowriter.

Stage D:

(1) If the computer must be released to others the operator should wait until the computer starts punching and then lift break point 8. He should depress "Manual Input" lever on flexowriter.

(2) When the computer halts, the operator should turn on the flexowriter power, insert tape number four into the mechanical reader and depress "One Operation", "Clear Counter", "Normal", "Start". When the light appears on the flexowriter, the operator should depress "tape feed" and tear off the data output. He should depress "tape feed" again and lift the manual input lever. This will result in a retention, on tape, of valuable hexadecimal data. It should be carefully labelled.

Stage E:

(1) If the operator wishes to continue, at a later date, from D(2) he should load the program (tape number three) by depressing "one operation", "clear counter", "normal, "start" after tape number three has been inserted in the photoreader and the "input selector switch" has been turned to "reader". The same procedure should be used to load the

hexadecimal data of D(2).

(2) The operator should turn the punch power on and turn the "input selector" switch to "typewriter". When the flexowriter light appears after "one operation", "clear counter", "normal", "start", the operator should type .0002445'. He should depress all break points and the "transfer control" button should be as in D(2). Depressing "Start" button will cause the computer to continue from D(2).

SAMPLE DATA INPUT

```
;0000951'+0110003'072900'000''
;0001029'+0150014'018820'000'-'
;0001031'+0110003'591000'000''
;0001039'+0110003'591000'000''
;0001100'+0150014'081490'000''
;0001130'+0110003'473000'000'-'
;0001132'+0110003'473000'000''
;0001153'+0110001'021100'000'-'
;0001201'+0110001'137600'000'-'
;0001263'+0110001'021100'000'-'
;0001315'+0110003'591000'000''
;0001335'+0110003'562000'000''
;0001353'+0110003'562000'000'-'
;0001363'+0150014'018820'000'-'
;0001505'+0110001'137600'000'-'
;0001555'+0110001'021100'000'-'
;0001640'+0110003'072900'000'-'
;0001661'+0110001'137600'000'-'
;0001700'+0110003'562000'000''
;0001740'+0110001'137600'000'-'
;0001762'+0100000'986000'000''
;0002457'xz0003';0002501'xz0003'.0000000'


;0005000'+0700000'
383000'000''
003371'000''
049550'000''
062000'000''
000519'900''
376991'119''
350000'000''
+0230009'
000123'000''
006420'000'-'
,0000006'''''''.
+0100000'
192000'000''
+0430007'
000223'000''
000149'000'''''''''
+0230009'
128000'000''
'''
+0130009'
085500'000''
```

```
,0000036'''''''
```

Explanation of input data.

;0000951' means "start filling into track 09 sector 51".

+0150014' means "the next 1 word, 9 digits long has the decimal point after the fifth (assumed) character and is to be multiplied by 2^{-14} before storing". Leading zeros need not be punched. "Each word must be composed of three parts: the most significant 6 digits, the next 3 significant digits and an extra stop code if positive or - if negative".

xz0003' this is used as an exponent. All exponents are stored at q = 29 in the subroutines used for floating point arithmetic. xz0003 means that the mantissa as a decimal must be multiplied by 1000. A negative exponent is stored as the complement of the positive exponent as for example ;0002431',0000001'wwwwwwwj' means "Track 24 sector 31 is to contain the hexadecimal word wwwwwwwj which is -1 at q = 29".

Starting in track 50 sector zero, the following data must be stored:

r_α, L_α, m, r_β, L_β, f_α, f_β real part $i_{\alpha 1}$, imaginary part $i_{\alpha 1}$, real part $i_{\alpha 2}$, imaginary part $i_{\alpha 2}$, real part $i_{\beta 1}$, imaginary part $i_{\beta 1}$, initial angular displacement from stator to rotor (radians) J,R.

Starting in track 50 sector 20 the stator phase voltage must be stored.

Starting in track 50 sector 22 the rotor phase voltage must be stored.

Starting in track 50 sector 59 the difference between rotor and stator frequency (radians/sec).

Starting in track 24 sector 31 the exponent for the contents of sector 32 track 50 sector 59.

DATA OUTPUT

Three rows of data will be output:

Row #1 real and imaginary parts, positive and negative sequence stator currents.

Row #2 real and imaginary parts, positive and negative sequence rotor currents.

Row #3 Angular acceleration of rotor electrical radians per second per second; angular velocity of rotor electrical radians per second; displacement of rotor in radians (a floating point number) as for example .1919999810 1 - would mean .0191999981 radians; electrical displacement of rotor from stator in radians (a floating point number); finally the time elapsed from start of study, in seconds.

APPENDIX C

SUPPLEMENTARY GRAPHS AND DATA

I. FRICTION AND WINDAGE BY ELECTRICAL MEANS

Figure 1 was used as a rapid method of estimating the power lost in carbon and copper when the shunt wound direct current machine was running. Table I displays the data used in making Fig. 4. "Speed" was measured by a carefully calibrated Strobotac, "potential" was measured across the armature terminals only, "current" was measured by a millivoltmeter connected across a carefully matched shunt. "Power" was immediately calculated as the product of current and potential and was, of course, the gross power input to the armature. "Copper Power" was determined from Figure 1 and subtracted from "Power" to give "Net Power". The data from "Net Power" were used to produce the curves marked "A.C. End + D.C. End" and "D.C. End Alone" shown in Fig. 4. The difference between the two curves was used to determine the curve marked "A.C. End Alone".

Figures 2 and 3 were attempts to gain insight as to the nature of friction and windage of bearings and to exclude brush friction in the alternating current machine. The writer could only conclude that considerable effort would be needed to analyse the phenomena into an analytical equation and that such an equation would not be of much use in any case since the results were not reproduceable and as such would be of little use.

FIG. 1

ARMATURE POWER LOSS AT STANDSTILL

WESTINGHOUSE OF EAST PITTSBURG

STYLE 65 E 659 TYPE SK D.C. MOTOR

FRAME 53 7.5 H.P. 115 VOLTS 53 AMPERES

900/1200 R.P.M. SERIAL 4978625

117A

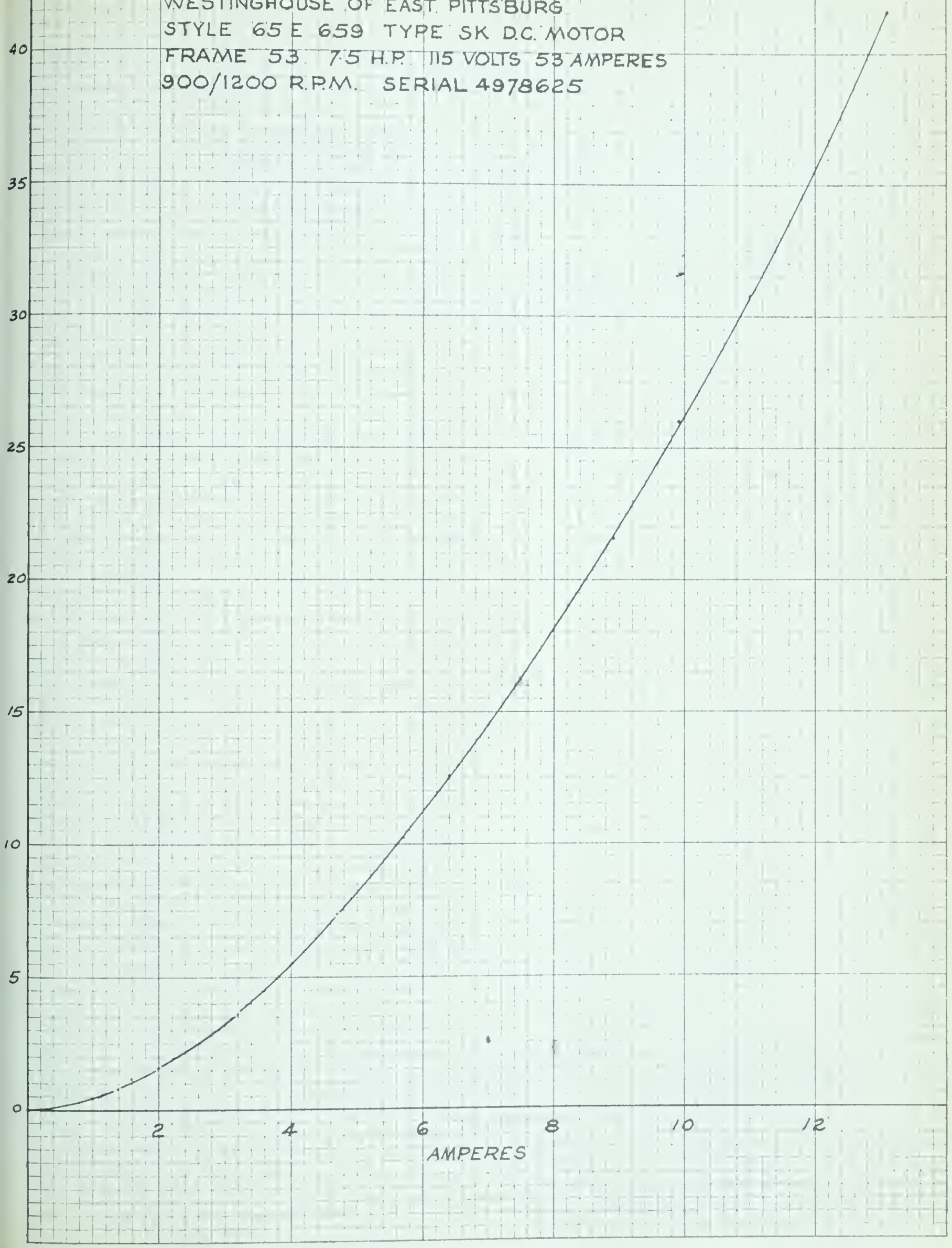


FIG. 2

FRICTION AND WINDAGE POWER
BRUSHES LIFTED FROM A.C. MACHINE
WESTINGHOUSE OF EAST PITTSBURG
5 KVA 110/220 v, 26/13 A
90 % P.F. 1/3/6 PHASE
60 CPS 1200 RPM
EXC. 4.7A 110 v
S.O. 65 E 658
SERIAL 4978626
DATE: FEB. 7, 1962

117 B

A.C. END COUPLED

A.C. END UNCOUPLED

FRICTION WINDAGE
AND VISCOSITY POWER
OF A.C. END ONLY

WATTS

450
400
350
300
250
200
150
100
50

200
400
600
800

SPEED RPM

FIG. 3

FRICTION AND WINDAGE POWER
BRUSHES LIFTED FROM A.C. MACHINE
WESTINGHOUSE OF EAST PITTSBURG
5 KVA 110/220 v, 26/13 A
90% P.F. 1/3/6 PHASE
60 CPS 1200 RPM
EXC. 4.7 A 110 v
S.O. 65 E 658
SERIAL 4978626
DATE: FEB. 9, 1962

117C

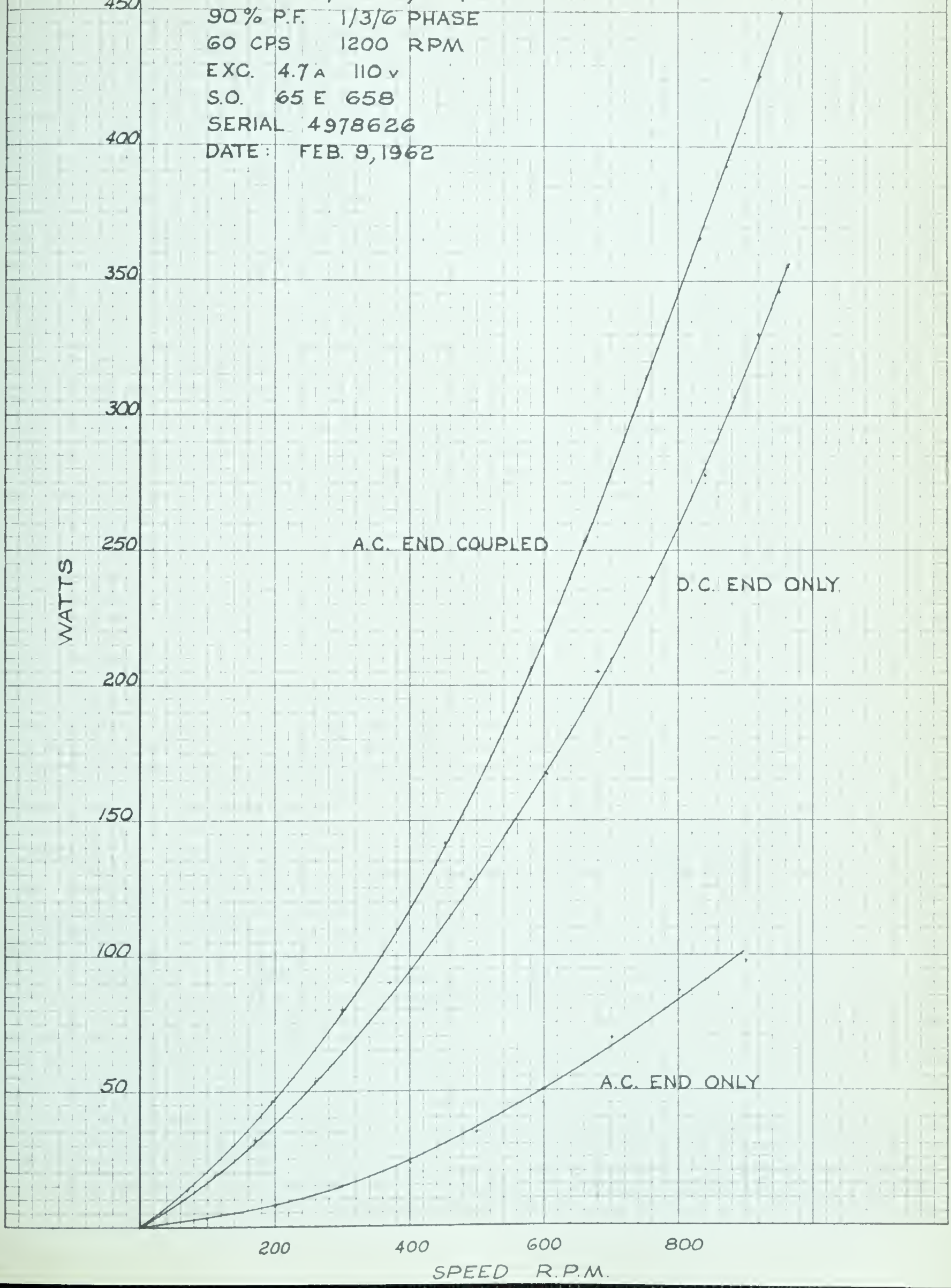


FIG. 4

FRICTION AND WINDAGE (INCLUDING SLIP RINGS)

WESTINGHOUSE OF EAST PITTSBURG

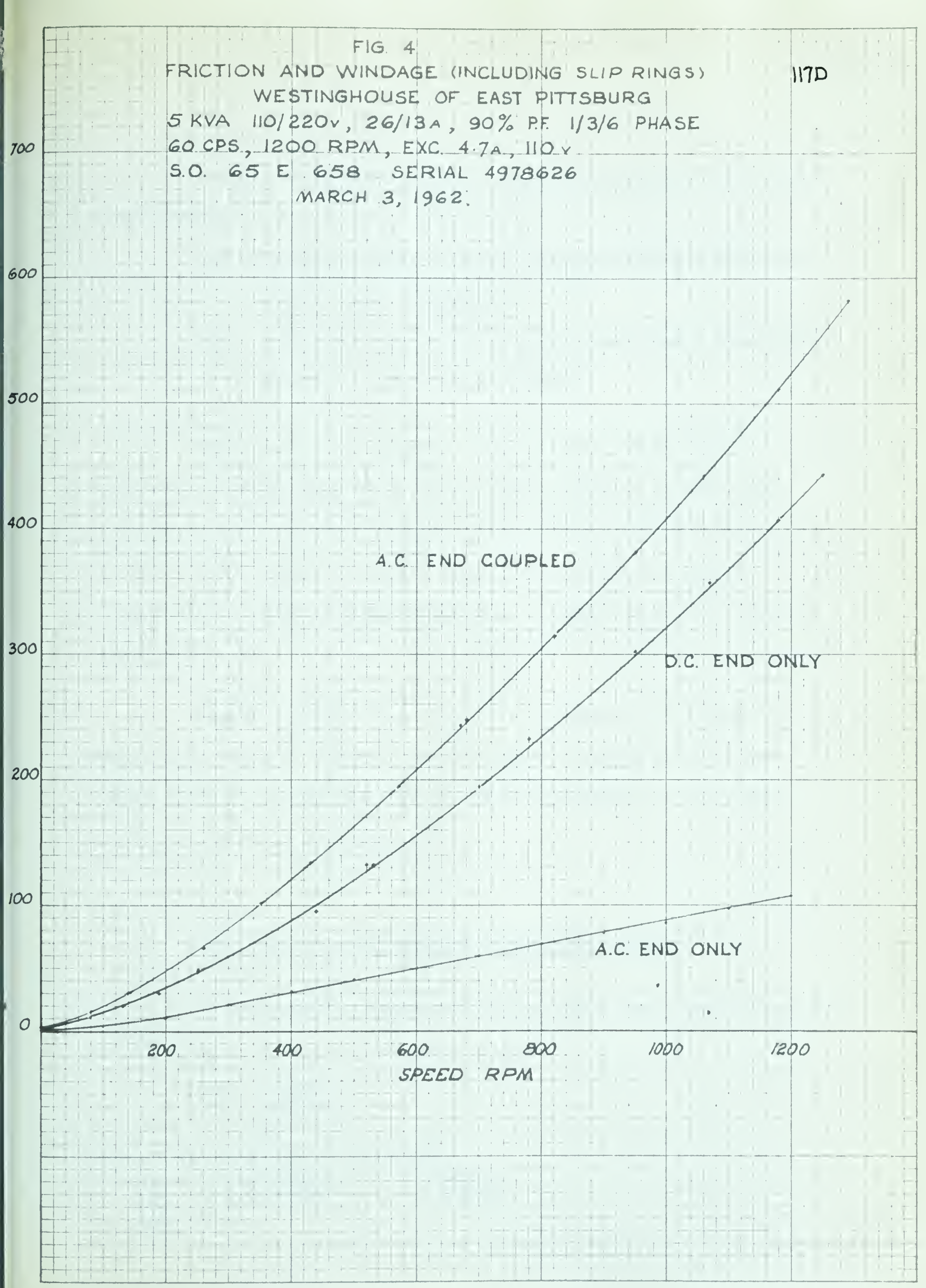
5 KVA 110/220v, 26/13A, 90% P.F. 1/3/6 PHASE

60 CPS., 1200 RPM, EXC. 4.7A., 110 V.

S.O. 65 E 658 SERIAL 4978626

MARCH 3, 1962.

117D



The following phenomena associated with friction and windage were expected:

(a) a portion of the friction and windage should have been linearly speed dependent.

(b) a portion of the friction and windage should have been dependent on the square of speed.

From equation 1 Chapter III, the power consumed in mechanical damping would be $R(\dot{\theta})^2$ but this quantity, R, would be measured in foot-lbs-sec^{+2} radians^{-2} whereas the quantities that could be derived from Figs. 2, 3 and 4 would be watt-sec^{2} revolutions^{-2}. If the quantities could be derived from Fig. 4, then the result should be multiplied by 67.1 to convert watts-min^{2}-rev^{-2} to foot-lbs-sec-radians^{-2}.

Figure 4 clearly has a square law component, although the coefficient would be difficult to determine. Figures 2 and 3 have marked square law behaviour but the overall behaviour is such that one could not trust the results.

II. FRICTION AND WINDAGE BY MECHANICAL MEANS

As outlined in Chapter III Section III, simple damped harmonic motion would lead to an approximate period

$$\tau = \frac{2\pi J}{\sqrt{(wrJ - R^2)}}$$

From θ at $t = \tau$ one would obtain

$$\frac{\theta_\tau}{\theta_o} = e^{-\frac{R}{2J}\frac{2\pi J}{\sqrt{wrJ - R^2}}} = e^{-\frac{\pi R}{\sqrt{wrJ - R^2}}}$$

Since the amplitude could be directly measured and θ_τ was measured, all values necessary could be determined.

at $t=0$, the weight was 17.5 inches above datum

at $t=\tau$, the weight was 8.75 inches above datum

at $t=\infty$, the weight was 3.25 inches above datum

The radius of the shaft was 1.118 inches (including one half the thickness of the wire). The linear slope of the figure 4 was used to estimate the frictional force and in turn the retarding torque was estimated at 7.39 inch-pounds.

Thus the net torque was estimated at 11.9 inch-pounds

at $t=0$:

$$14.25 = A_o e^{0} \cos(0)$$

$$= A_o$$

The period was observed to be 2.85 seconds and thus

$$4\pi^2 J^2 = (2.85)^2 (TJ - R^2)$$

$$= (2.85)^2 (11.9J - R^2)$$

at $t=\tau$:

$$5.5 = A_o e^{-R\tau/2J} \cos 2\pi$$

and $e^{-R\tau/2J} = \frac{5.5}{14.25}$ or $\frac{R\tau}{2J} = 0.95$

Hence

$$R = 0.666\,J$$

$$R^2 = 0.444\,J^2$$

Then

$$J = 2.68$$

$$R = 1.783$$

or instead of inch-lb-sec^2 radian^{-1} and inch-lb-sec radian^{-1} respectively, J = 0.223; R= 0.149 foot-lbs-sec^2 radian^{-1} and foot-lb-sec radian^{-1} respectively.

TABLE I

MECHANICAL LOSSES DETERMINATION: SUPPLY FROM D.C.
D.C. MACHINE COUPLED TO A.C.

Speed	Potential	Current	Power	Copper Power	Net Power	D.C. Field Excitation Constant 1.20 Amps.
1295	116.9	5.05	590	8	582	
1180	110.8	4.70	520	7	513	
1060	100.0	4.50	450	7	443	
950	90.0	4.30	387	6	381	
820	78.1	4.10	320	6	314	
680	64.8	3.90	253	5	248	
670	64.0	3.90	250	5	245	
566	53.8	3.71	199½	5	195	
433	41.6	3.30	137½	3.8	134	
$\frac{1410}{4}$=352	33.9	3.09	104.8	3.4	101.4	
$\frac{1040}{4}$=260	24.9	13.61	67.7	2.6	65.1	Current ÷5.
142.0	13.9	11.50	32.0	2.1	29.9	
85.0	8.59	10.10	17.3	1.8	15.5	
39.0	4.2 ±.2	8.80	7.4	1.2	6.2	

MECHANICAL LOSSES : SUPPLY FROM D.C. : D.C. MACHINE ONLY

1255	117.7	3.80	447	5	442	
1180	111.0	3.71	412	5	407	
1071	101.0	3.60	363	4	359	
955	90.2	3.40	306	4	302	
785	74.9	3.19	239	4	235	
695	66.0	3.00	198	3	195	
530	51.0	2.61	133	2	131	
525	50.4	13.40	135	3	132	Current ÷5.
420	40.0	12.10	96.8	2.2	94.6	
$\frac{760}{3}$=253	24.4	10.00	48.8	1.5	47.3	
186	18.0	9.20	33.1	1.2	31.9	
126	12.9	8.15	21.0	1.0	20.0	
78	8.05	7.70	12.4	1.0	11.4	
24	6.25	6.85	8.5	.8	7.7	

APPENDIX D

ARTIFICIAL DAMPING

The writer altered the program to study the case where a torque is applied to the rotor shaft according to the formula:

$$T_a = -K(\dot{\theta} - \dot{\theta}_o)$$

where $\dot{\theta}$ is the actual velocity

$\dot{\theta}_o$ is the ideal velocity.

The new differential equation is

$$J\ddot{\theta} + R\dot{\theta} = T_e - K(\dot{\theta} - \dot{\theta}_o)$$

where T_e is the developed electromagnetic torque in the doubly excited induction machine.

Then

$$\ddot{\theta} = \frac{T_e}{J} - \frac{1}{J}\left\{(R+K)\dot{\theta} - K\dot{\theta}_o\right\} = \frac{T_e}{J} + \frac{K+R}{J}\left\{\frac{K\dot{\theta}_o}{K+R} - \dot{\theta}\right\}$$

With

$$\frac{K}{K+R} = 0.96514 \qquad R = 0.149$$

$$\frac{K+R}{J} = 19.168 \qquad J = 0.223$$

an improvement was noted but stability was not achieved. For the above data $K = 4.1252$ (ft-lbs-sec radian^{-1}) which is, in reality, a very small value in comparison to what can be achieved.

It should be noted that the torque given by

$$T_a = -K(\dot{\theta} - \dot{\theta}_o)$$

is very close to the torque developed by a shunt wound direct current

motor.

The accompanying two coding sheets demonstrate the changes required to study the phenomena associated with the externally applied torque. (See statement (15) Appendix B).

LGP-30 CODING SHEET

NO. 1

PAGE ____ OF ____

B NO ____ PROG NO ____ PREP BY ____ CK'D. BY ____ DATE ____

OBLEM ____ TRACK ____

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP.	INSTRUCTION ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		☒					
		0 8 0.0					
		0.1					
		0.2					
		0.3				☒	
		0.4					
		0.5					
		0.6					
		0.7				☒	
		0.8					
		0.9					
		1.0					
		1.1				☒	
		1.2					
		1.3					
		1.4					
		1.5	x B 5 0 5 8			☒ S_0 @9	Approx 26.991118
		1.6	x M 5 0 4 5			$\frac{K}{K+R}$ @0	Approx 0.96514.
		1.7	x S 5 0 5 3			$\dot{\delta}$ @9	Unknown & Variable.
		1.8	x M 5 0 4 7			$\frac{K+R}{J}$ @5	Approx 19.168.
		1.9	x N 0 8 0 5			☒ 1@28	$\ddot{\delta}_{damping}$ @11
		2.0	x U 2 1 2 3				
		2.1					
		2.2					
		2.3				☒	
		2.4					
		2.5					
		2.6					
		2.7				☒	
		2.8					
		2.9					
		3.0					
		3.1				☒	

C-94195 MCBEE TORONTO CANADA

☒ CONDITIONAL STOP CODE

☒ CARRIAGE RETURN

The McBee Company Limited

JAN 57

LGP-30 CODING SHEET
NO. 1

PAGE ____ OF ____

NO ____ - ____ PROG NO ____ PREP BY ____ CK D BY ____ DATE ____

BLEM CORRECTIONS TO ALLOW ARTIFICIAL DAMPING. TRACK ____

PROGRAM INPUT CODES	STOP	LOCATION	INSTRUCTION OP.	INSTRUCTION ADDRESS	STOP	CONTENTS OF ADDRESS	NOTES
		21 00					
		01					
		02					
		03				☒	
		04					
		05					
		06					
		07				☒	
		08					
		09					
		10					
		11				☒	
		12					
		13					
		14					
		15				☒	
		16					
		17	X U	0815			
		18					
		19				☒	
		20					
		21					
		22					
		23	X A	5052		☒	
		24	X U	2125			
		25					
		26					
		27				☒	
		28					
		29					
		30					
		31				☒	

C94185 MCBEE TORONTO CANADA

☒ CONDITIONAL STOP CODE ☒ CARRIAGE RETURN

The McBee Company Limited

JAN 57

APPENDIX E

CONSTANT CURRENT REGULATOR

Shunt field heating in the separately excited shunt connected direct current motor resulted in some drift in shunt field current. Inductive effects and possibly other unknown or undefined functions such as armature reaction would have made many of the experiments invalid. Accordingly the writer sought methods to regulate the shunt field current.

Assistant Professor K.G. Clarke kindly loaned the writer two power transistors and one zener diode and, far beyond the call of duty, designed a circuit using these components which provided remarkably constant current. The circuit as designed by Mr. Clarke is included herein and a detailed method of operating the device is also given.

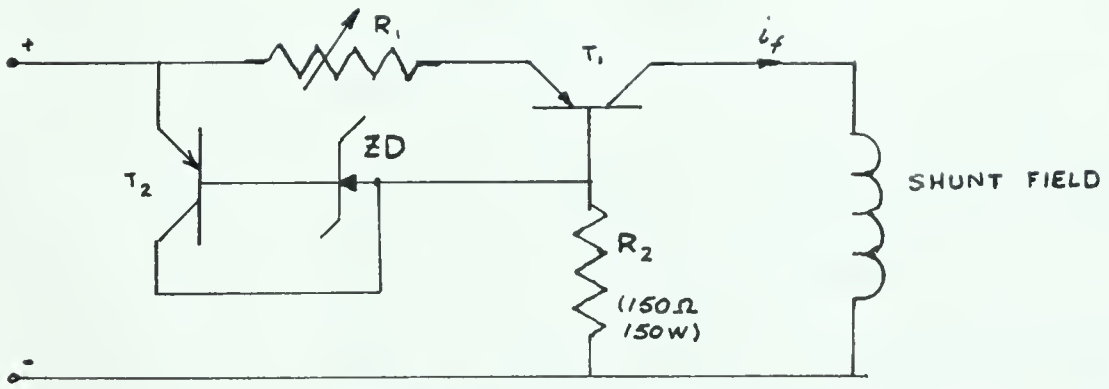


Fig. 1 CURRENT REGULATOR.

The function of the zener diode was to provide a comparatively small reference current for R_2 and the function of T_2 was to amplify this reference current to such a level that the combined current would be at least ten times the base current of T_1.

With a drop in field current the bias across the transistor from emitter to base would tend to decrease and the mutual conductance would tend to rise allowing more collector current.

Since an increase of R_1 beyond a certain maximum would produce an emitter potential less than base potential and result in negative base current, care had to be exercised in use of the equipment. Consequently the following procedure was adopted:

(a) The value of R_1 was set to minimum.

(b) The variable voltage supply V_1 was applied at a value which could not have delivered more than desired current to the field windings.

(c) If the product of emitter-collector voltage and collector current exceeded 10 watts V_1 was reduced, if not 10 watts the value of R_1 was increased until the product was 10 watts or the emitter-collector voltage reached 20 volts whichever occurred first.

It was observed that the emitter to collector voltage could be controlled almost exclusively from V_1 while R_1 controlled the current almost exclusively. In essence, any field heating effects were cancelled by a reduction of emitter-to-collector voltage and this

voltage had to be kept reasonably high in order to avoid much adjustment of the apparatus. So long as the emitter was higher in potential than either the base or collector, the operator could be certain that the field current was constant.

APPENDIX F

SUMMARY OF ELECTRICAL AND MECHANICAL DATA

I. ELECTRICAL DATA

With the rotor removed from the machine, the resistances and reactances of each phase were determined as follows:

(a) Three single phase wattmeters were selected having nearly identical impedances in order to avoid unbalancing the three phase system.

(b) The star point of the rotor was made accessible.

(c) All three wattmeters had their potentials referred to the star point.

(d) From data collected the following constants were calculated:

(1) $|Z_\beta| = (0.205 \pm 0.005)$ ohms

(2) $r_\beta = (0.062 \pm 0.010)$ ohms

(3) $x_\beta = (0.196 \pm 0.015)$ ohms

The voltage was kept sufficiently low that hysteresis and eddy current losses would be negligible, the phase potentials being a little under four per cent of rated rotor phase potentials.

A similar procedure was used to determine the stator quantities. In this instance the stator phase potentials were kept below ten per cent of rated. The constants calculated for the stator are as follows:

(1) $|Z_\alpha| = (1.326 \pm 0.010)$ ohms

(2) $r_\alpha = (0.383 \pm 0.004)$ ohms

(3) $x_\alpha = (1.271 \pm 0.010)$ ohms

The writer noted that

$$\frac{|Z_\alpha|}{|Z_\beta|} = 6.47 \qquad \frac{x_\alpha}{x_\beta} = 6.50$$

$$\frac{r_\alpha}{r_\beta} = 6.18$$

A variation of less than 5 per cent is observed. The coefficients of self inductance are proportional to the square of the turns and the voltages are proportional to the turns. Hence the voltages are proportional to the square root of the reactances. If the stator voltage is 220 volts then the rotor voltages should be $\frac{220}{\sqrt{6.50}} = 86.3$ volts.

The writer found that stator potentials of 224, 227 and 223 volts required 86.2, 85.1 and 86.8 volts in the rotor before parallelling. This would indicate an error of perhaps two per cent which is entirely consistent with instrumental error and personal errors.

II. MECHANICAL DATA

With the procedure outlined in Chapter IV Section V the following constants were calculated:

(1) J = 0.223 (F.P.S. system)

(2) R = 0.149 (F.P.S. system)

III. MUTUAL INDUCTANCE

The mutual inductance was determined by applying the formula

$$m = \sqrt[3]{L_\alpha L_\beta}$$

The above formula tends to neglect leakage which would be of the order of three to six per cent and m could be in error by one and a half to three per cent. One could determine the mutual inductances from open circuit tests of the rotor but it has already been demonstrated that the results of the above formula are acceptable.

The value of m calculated was 0.04955 henries.

IV. SUMMARY

r_α = 0.383 ohms

L_α = 0.003371 henries

m = 0.04955 henries

r_β = 0.0620 ohms

L_β = 0.000519 henries

J = 0.223 (F.P.S. system)

R = 0.149 (F.P.S. system)

B29805